# Development

AND

# Electrical Distribution of Water Power

BY

LAMAR LYNDON

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# PREFACE.

It is to be understood that this work is not a text-book on electricity, hydraulics, concrete work, nor construction engineering. The purpose has been to produce a purely engineering treatise in which all the salient facts concerning the hydraulic development of power, its conversion into electrical energy, and its transmission over long distances, are collated, and their interdependence shown.

With but few exceptions, no basic principles of electricity are set forth nor are the derivations given of the formulæ used.

With the many excellent works on hydraulics and electricity now published, it is needless to reproduce their contents here. It is with the relationships between the available power, methods of development, the machinery and apparatus employed, and the final use to which the energy will be put, that this book is concerned. It is to be noted that the use of mathematics has been studiously avoided and the text may be followed understandingly by any one having an elementary knowledge of algebra.

The descriptions of plants, taken from prominent technical periodicals, is believed to be a valuable addition and innovation, both in that the principles set forth in the main body of the book are here shown in concrete form, practically applied, and that they constitute an aggregated expression of the broad ideas held on this subject by that portion of the engineering profession experienced in this class of work.

The author has found, in his own practice, that the best way to investigate a problem is to discover all that has been done in

the same field by engineers of ability, and take this combined knowledge and experience as the starting point. Such a method, however, involves considerable work and loss of time in searching through the files of the technical journals. Assembled here, after selection from among a large number, it is believed that the ease with which these examples may be referred to justifies their reprinting and enhances the usefulness of this book.

The author wishes here to express his appreciation of the courtesy extended by the editors of *The Electrical World*, *The Electrical Review*, *The Engineering Record*, and *The Engineering News*, who have kindly permitted the use of abstracts of descriptions of plants from their respective periodicals.

LAMAR LYNDON.

NEW YORK, October, 1907.

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## PART I.

### CHAPTER I.

#### GENERAL CONDITIONS.

THE most important factor in the development of a water power is to determine, in advance, the actual amount of power that may be obtained continuously over a long period of years. Failure to give this matter the attention and careful investigation which its importance deserves has resulted in financial disaster in many instances. Too often, engineers survey hydraulic properties, and report that the flow of water is a given quantity per second, and therefore the power obtainable is a certain amount. Such computations are correct *for the particular day on which the survey is made*, but obviously the amount of water flowing, and, therefore, the power, may change within a few hours. Laymen who know nothing of engineering are familiar with the variation in the flow of streams with the time of the year, and in some years the flow is less or greater for a certain season than it normally is at the same period.

At times, water-power development is undertaken on the basis of the ability to supply a given amount of power for the greater part of the year, and a less amount during the short time of the dryest season or when the stream is so greatly flooded that operation of water wheels is impossible. This also is an erroneous basis on which to determine the value of a water power unless there is some class of industry to which the power may be sold, which

can use intermittent power and which can suffer stoppage or reduction of its operations without material loss. In this case, if the amount of power to be taken by the intermittent power-users be previously known, together with the frequency and duration of the shut-downs they can allow, a fairly accurate conclusion as to the value of the power and the advisability of developing it may be formed.

Still other developments are made having auxiliary steam plants, which are used to help out the water power when the stream flow is too low to furnish the required energy. This is an admirable arrangement, where the value of the power sold, during the several months when water in plenty is available, is sufficient to pay the cost of operating with the assistance of steam, during the short time of low water. Usually, however, the proper basis on which to fix the amount of available power is to take a series of records of stream flow during the times of maximum and minimum flow. These observations, to be reliable, should extend over several years, or over one year which is admittedly the dryest known in a number of years.

In the United States, the Government has long maintained gauges at different points on most of the large rivers, and their records are available and may be used in computing the available power without making any additional observations on the stream itself. In many countries, however, the engineer is dependent on his own observations, and as these cannot be carried over a long number of years he must fall back on the methods of computation from the rainfall, the drainage of the stream, the local conditions as to character of the country, its vegetable growths, and whether its geological formation is such that underground storage reservoirs exist which supply springs that continue to feed the streams during dry weather. With these data, reinforced by experience, a fairly accurate determination of the minimum stream flow may be arrived at.

The character of the underbrush, shrubbery and trees, their extent; the proportion of wooded area to that denuded of trees,

the proportion under cultivation, all have a marked influence on the variation in the flow. Trees and shrubs tend to hold the rain water and make it move slowly toward the stream—so slowly that much of it is absorbed into the earth and then reaches the river or its tributary creeks only by percolation which greatly retards its movement. These effects combine to equalize the amount of water which is given to the stream by each rainfall. Rains come intermittently and are of varying volume. The flow of streams would be equally intermittent and variable as to volume if it were not for these retarding influences. Cases are on record where water powers, which were at one time good and satisfactory, have been injured by subsequent cutting away of timber and underbrush over the drainage area of the streams supplying them. These power-plants are now subjected to heavy floods in the wet season of the year, and the available water in the dry season is smaller than it formerly was. Therefore, this factor must be given due consideration. Where springs are numerous, they tend to keep the stream flow up in dry weather and these are valuable when they discharge enough water to be of real assistance.

The character of the industries to which the power will be transmitted also has to be considered. If the general use is for lighting, for driving cotton mills, factories, and the like, *the only power that can be counted on in the development is that produced by the smallest flow of water that occurs during the entire year.* Obviously, if an amount of power, greater than this minimum flow will furnish, be sold to users, a time will come when some or all of them will have to reduce their working capacity, and this result tends to prevent consumers making satisfactory contracts for power with the development company.

The minimum flow sometimes may be increased by means of storage. When a dam is built across a stream and a lake of considerable area is formed, the water thus accumulated may be partially drawn off during the dry season, the total water passed through the turbines being that furnished by the stream plus that of drainage from the lake. In some cases, when the power is

used only ten hours per day and the storage area is sufficiently great, the water which flows during the night is accumulated in the lake, and on the following day the water available for power is that supplied by the stream flow plus that impounded during the previous night. In this way, the power furnished by a given stream may be nearly doubled.

For the purpose of forming extensive storage lakes, dams of great height and length are often constructed, where a small dam, further up the stream, and a canal or flume leading to the foot of the falls, costing much less, would serve just as well, if the question of storage were not involved.

In order to determine the value of a water power and whether or not the investment of its cost of development is warranted, the following data must be obtained:

(1) Variation in quantity of stream flow.

(2) Amount of power (gross) available at *minimum* flow.

(3) Cost of hydraulic development (*i.e.*, dam, canal, tail race, forebay, head-gates, flumes, overflowed land, riparian rights).

(4) Cost of power station and foundations.

(5) Cost of generating equipment (*i.e.*, water-wheels, governors, generators switchboard, transformers, miscellaneous equipment).

(6) Cost of transmission line (*i.e.*, wire; insulators, poles; cross-arms; braces, lag screws).

(7) Labor, freight, and cost of erection on all work as above.

(8) Cost of operation per annum.

(9) Price at which power may be easily sold in the localities reached by the transmission lines.

(10) Annual profit.

The annual profit as thus computed shows whether the interest on the cost is sufficient to make the investment a good one.

It is, of course, assumed that there is a market for the power, or that the conditions justify the belief that cheap power will build up a locality and bring power users within the radius of distribution of the projected plant.

The quantity of stream flow and its variation are arrived at in one of the following ways:

(a) From observations extending over a number of years.

(b) From records of rainfall and drainage area of stream down to location of power house.

(c) From a few observations made at the time of known low water.

Where possible, all of these means should be used to check the final result.

From (a) and (b) the maximum as well as the minimum flows are obtained, and either is, therefore, preferable to (c) alone. Neither (b) nor (c) alone should ever be accepted as final, but the two always used together to check each other.

The maximum flow must be known, so that the dam may be designed to withstand it, and the spillway—that is, the crest of the dam over which the water flows—made long enough to allow the maximum volume of water to pass over it without an excessive rise in the height of the water over the dam.

Abnormal increase in the height of water above the spillway endangers the dam and may result in its being swept away.

To determine the flow where no data are available, it is customary to proceed as follows:

Select two points along the stream about three hundred feet apart. These should be located somewhere along the stream where it runs straight without curves, bends, falls, or eddy whirls, and the current is down the middle of the stream—not near either bank. Make a cross-section survey of the stream at both points, and determine the area of each section in square feet. Take the average of these two sections—that is, add the areas of the two sections together and divide their sum by 2. This gives the mean section. At times of high and of low water, take the velocity of the stream by means of a float which sinks deeply into the water. The float is put into the current of the stream about four hundred feet above the upper reference point, so that by the time it has been carried down to this point it has attained the velocity

of the stream. Observe accurately the time required for the float to travel from the upper point to the lower one. Knowing the time in seconds and the number of feet the two points are apart, the velocity of the stream flow, at the times these observations are taken, may be computed.

The *average* velocity of the stream is, however, less than that of the main stream current, and it is customary to assume the average rate of flow as 80 per cent of that of the float.

The number of cubic feet per second is then computed by multiplying the *average* cross-section of the stream by the average rate of flow.

To make a survey of the cross-sections of the stream it is usual to select a time of low water and by means of a surveyor's level take the differences in level from the surface of the water out to either side of the stream to such a distance that the maximum high-water point is reached, care being taken to move outward from the stream at right angles to its direction of flow. Observations are made at intervals of from two to twenty feet, depending on the variation in the contour of the banks, and the distance from the water surface out to the maximum high-water level.

The cross-section of the stream itself is then determined. The best way to do this is to stretch a strong iron wire, about $\frac{3}{32}$ of an inch in diameter, across the stream, this wire having been previously marked by small metal or wooden tags spaced along it at equal intervals. The distance apart of the tags should be not more than ten per cent. of the width of the stream. With a steel tape, weighted at one end by a heavy plumb bob, measure the depth of the water at each marking on the transversely stretched wire, using a small row-boat when necessary. From these data the cross-section may be mapped and computed.

This is done by assuming some scale on the paper, say $\frac{1}{16}$ of an inch, as equal to one foot of horizontal distance, and some other greater scale, say one inch, as equal to one foot of vertical measurement.

Computing the area of the cross-section of the water may

be done by any method of integrating irregular surfaces. A simple approximate way is to add together all the observed depths and divide this result by the number of observations. This gives the average depth. Multiply this average depth by the width of the stream, in feet, and the product will equal the cross-section of the stream in square feet.

The float should be made of a piece of wood about three feet long and from six to ten inches in diameter. Weights should be


FIG. 1.

fastened to one end of the piece so that it will float vertically, with one end submerged and the other projecting only an inch or two above the surface of the water.

In order to observe from the bank the position of the float,

it is usual to fasten a small piece of red cloth to a rod or piece of wire and drive this rod into the upper end of the float.

The distance apart of the two points selected to observe the float velocity should be accurately measured and stakes driven in the ground near the water's edge, to fix these reference points.

The foregoing instructions are for determining the flow of moderate and large-sized streams.

In measuring small streams it is more accurate and convenient to construct a weir dam such as is shown in Fig. 1. This is made of boards as is indicated, with a notch *B* extending across about two-thirds the width of the stream and deep enough to easily pass all the water through it. The edges of the notch must be sharply bevelled as shown, the bevelling being on the down-stream side.

Ten feet up the stream from the weir dam a stake *E*, having a smooth upper surface, should be driven. The upper face of this stake must be exactly at the same level as the lower edge of the notch *B*. On this stake the depth of the water above the edge of the notch must be measured. Never measure this depth at the notch.

The formula for determining the cubic feet per second of flow is:

$Q=3.33 \times (b - 0.2h)\, h^{\frac{3}{2}}$ in which

$Q$ = cubic feet per second,

$b$ = length of the notch measured in feet,

$h$ = depth of water over notch measured in feet.

In order to obviate the necessity of making computations from this formula, the following table is given, which shows the cubic feet per *minute* with various depths of water in inches over the notch for each *inch* length of notch up to depths of $24\frac{7}{8}$ inches.

Column No. 1 is the depth in inches over the notch.

Column No. 2 is the flow in cubic feet per minute corresponding to the depth as given in column 1 for *each inch length* of the notch.

Thus, for a depth of 10 inches the flow is 12.71 cubic feet per minute for each inch length of notch. Therefore a notch 40 inches wide with 10 inches depth of water over it will pass $40 \times 12.71 = 508.4$ cubic feet per minute.

TABLE No. 1.—WEIR TABLE—FLOW FOR EACH INCH IN WIDTH.

| Inches Depth. | | 1/8 | 1/4 | 3/8 | 1/2 | 5/8 | 3/4 | 7/8 | Inches. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .40 | .47 | .55 | .65 | .74 | .83 | .93 | 1.03 | 1 |
| 2 | 1.14 | 1.24 | 1.36 | 1.47 | 1.59 | 1.71 | 1.83 | 1.96 | 2 |
| 3 | 2.09 | 2.23 | 2.36 | 2.50 | 2.63 | 2.78 | 2.92 | 3.07 | 3 |
| 4 | 3.22 | 3.37 | 3.52 | 3.68 | 3.83 | 3.99 | 4.16 | 4.32 | 4 |
| 5 | 4.50 | 4.67 | 4.84 | 5.01 | 5.18 | 5.36 | 5.54 | 5.72 | 5 |
| 6 | 5.90 | 6.09 | 6.28 | 6.47 | 6.65 | 6.85 | 7.05 | 7.25 | 6 |
| 7 | 7.44 | 7.64 | 7.84 | 8.05 | 8.25 | 8.44 | 8.66 | 8.86 | 7 |
| 8 | 9.10 | 9.31 | 9.52 | 9.74 | 9.96 | 10.18 | 10.40 | 10.62 | 8 |
| 9 | 10.86 | 11.08 | 11.31 | 11.54 | 11.77 | 12.00 | 12.23 | 12.47 | 9 |
| 10 | 12.71 | 13.95 | 13.19 | 13.43 | 13.67 | 13.93 | 14.16 | 14.42 | 10 |
| 11 | 14.67 | 14.92 | 15.18 | 15.43 | 15.67 | 15.96 | 16.20 | 16.46 | 11 |
| 12 | 16.73 | 16.99 | 17.26 | 17.52 | 17.78 | 18.05 | 18.32 | 18.58 | 12 |
| 13 | 18.87 | 19.14 | 19.42 | 19.69 | 19.97 | 20.24 | 20.52 | 20.80 | 13 |
| 14 | 21.09 | 21.37 | 21.65 | 21.94 | 22.22 | 22.51 | 22.79 | 23.08 | 14 |
| 15 | 23.38 | 23.67 | 23.97 | 24.26 | 24.56 | 24.86 | 25.16 | 25.46 | 15 |
| 16 | 25.76 | 26.06 | 26.36 | 26.66 | 26.97 | 27.27 | 27.58 | 27.89 | 16 |
| 17 | 28.20 | 28.51 | 28.82 | 29.14 | 29.45 | 29.76 | 30.08 | 30.39 | 17 |
| 18 | 30.70 | 31.02 | 31.34 | 31.66 | 31.98 | 32.31 | 32.63 | 32.96 | 18 |
| 19 | 33.29 | 33.61 | 33.94 | 34.27 | 34.60 | 34.94 | 35.27 | 35.60 | 19 |
| 20 | 35.94 | 36.27 | 36.60 | 36.94 | 37.28 | 37.62 | 37.96 | 38.31 | 20 |
| 21 | 38.65 | 39.00 | 39.34 | 39.69 | 40.04 | 40.39 | 40.73 | 41.09 | 21 |
| 22 | 41.43 | 41.78 | 42.13 | 42.49 | 42.84 | 43.20 | 43.56 | 43.92 | 22 |
| 23 | 44.28 | 44.64 | 45.00 | 45.38 | 45.71 | 46.08 | 46.43 | 46.81 | 23 |
| 24 | 47.18 | 47.55 | 47.91 | 48.28 | 48.65 | 49.02 | 49.39 | 49.76 | 24 |

If the depth of water over the notch is not an exact number of inches, column 3, 4, 5, 6, 7, 8, or 9 must be used. If the depth were 10¾ inches, the flow is given in column 8, and on the same horizontal line as the figure 10 in column 1; in this case the flow is 14.16 cubic feet per minute per inch length of notch. Similarly, the flow per inch width of notch may be found by taking the number out of the table from the column headed by the fraction of an inch, and opposite to the even number of inches shown by the depth measurement. Multiply the figure so taken by the width of the notch in feet, and the result is the cubic feet per *minute*. To reduce to cubic feet per second, divide the feet per minute by 60. Thus, 508.4 cubic feet per minute is equal to a flow of 8.47 cubic feet per second.

By making numerous observations at different seasons, sufficient records are finally obtained to settle, fairly well, the variation

in stream flow. This will afterward be modified by the available storage, which cannot be computed until the height of the fall is determined.

The fall is found by starting at the head of the shoals with an engineer's level, the lower end of the level rod being against the surface of the water for the first observation. The second observation is made with the level rod on the bank and succeeding observations are made with the level rod on the ground, working down to the foot of the shoals. When this point is reached the last observation is taken with the end of the rod against the surface of the water, and thus the difference in level between the head and foot of the shoals is determined.

Generally, the rod should be moved over to the water at intervals so that the drop at various points may be taken as well as the total difference in head. Where the whole drop is in one precipitous fall, only the difference in level between the top and bottom of the fall is obtainable or necessary.

After measuring the fall, the calculation of gross available power is very simple. A horse-power (gross) is produced when 8.8 cubic feet per second flows and falls a distance of one foot, or if one cubic foot per second falls a distance of 8.8 feet. Therefore, to find the power of a given fall, multiply the cubic feet flow per second by the fall in feet and divide the product thus obtained by 8.8. The result will be the gross horse-power of the fall. For instance, take a fall of 35 feet and a flow of 26 cubic feet per second: $35 \times 26 = 210$. $210 \div 8.8 = 103.4$ = gross H.P.

Where metric measurements are used these figures are changed as follows: one cubic metre of water per second falling through one metre will yield 13.2 H.P. gross.

For example, take 6 cubic metres of water per second falling through 12 metres. The product of 6 by $12 = 72$. Multiplying this by 13.2 the result gives 950 H.P.

These amounts, however, do not represent the power that may be actually utilized. In every machine or motor there is some loss. The loss in the best forms of water wheels is about

20 per cent. of the gross; so that the net power available at the turbine shaft is 80 per cent. of the gross. Thus, if the calculated gross-power is 100 horse-power, the amount that may be obtained at the turbine shaft is 80 H.P. Having determined the power obtainable at the turbine shaft at times of lowest water, if this is ample for all possible needs, the development may be made in the most inexpensive manner practicable for the particular conditions. If, however, the power is insufficient when the water is low, it becomes necessary to consider the question of storage.

In computing the available volume of water for storage, it must be remembered that the level of the reservoir can only be lowered a comparatively small amount. If the storage lake be drawn off too much and its level sinks too far, the head acting on the water-wheels will be diminished by an amount that will impair the operation of the plant. The drop in level of the reservoir should never exceed thirty per cent. of the effective head. In cases of extreme necessity this drop may be exceeded, but all calculations as to the amount of power obtainable from a given stream with storage should be based on a drop in head not exceeding thirty per cent.

The amount of storage is more often regulated by financial considerations than engineering possibilities. A concrete example will render the subject clear.

Consider a stream 220 feet wide having a fall of 50 feet in a distance of 3 miles. There are three methods of development possible. One is to cut a canal from the head of the shoals to the foot, this canal running level along the hillsides, and construct a small deflecting dam at the head of the shoals. The second is to build a dam at some point between the head and foot of the shoals, and run a canal the remaining distance to the foot of the shoals. The third method would be to build a large dam at the foot of the shoals and dispense with the canal.

Assume that the length of the three dams would be the same. Then their cost would be approximately as follows—assuming that the base of each dam is at an average depth of 10 feet below surface of the water:

First dam to be 4 feet above water surface, making a total height of 14 feet.

Second dam to be placed half-way down the shoals and to be 26 feet above the surface of the water, making the total height = 36 feet.

Third dam to be placed at the foot of the shoals and to be 51 feet above the surface of the water, making a total height of 61 feet.

The costs are: first dam, $5,500; second dam, $35,000; and third, $90,000.

The cost of canal to carry 300 cu. ft. per second will be about $10,000 per mile if cut through ordinary clay and no blasting is necessary. Adding the cost of canal cutting to that of the dam for each development, the total costs are—

1st development $35,000 (dam $5,000 + 3 miles of canal at $10,000);

2d development $50,000 (dam $35,000 + 1½ miles canal at $10,000);

3d development $90,000.

Assume the selling value of the power to be $15 per annum for 10-hour power; the minimum flow is 160 cubic feet per second, and this minimum flow lasts for 28 days in extreme dry seasons. The power desired is that furnished by 300 cubic feet per second.

With the first development at the lowest cost there is no storage capacity. In the second, the lake formed will be 1½ miles long and will have an average width of possibly 350 feet. This latter is determined by contours which are run at the time of surveying the water power, and the figure here taken is only an assumption.

The area of this lake is $1.5 \times 5,280 \times 350 = 2,772,000$ sq. ft. The depth down to which the lake may be drawn is 10 feet in this case (20 per cent. of the head). The total water available for storage is, therefore, $2,772,000 \times 10 = 27,720,000$ cu. ft.

If the amount is drawn off in 28 days the draft per day is 990,000 cubic feet and for 10-hour power the draft per second is 27.5 cubic feet. At an average head of 45 feet and 80 per cent.

efficiency the additional power obtained from storage during the dry season is $\frac{27.5 \times 45 \times .80}{8.8} = 112$ H.P., and its additional cost is $15,000.

This is over $133 per horse-power, which is a high figure for the hydraulic power only and not to be considered in localities where the yearly rental is not above $15 per horse-power.

Consider now the third possible development. The lake formed by its dam would be 3 miles long and (assumedly) average 450 feet wide. The volume of storage, with 10 feet depth of draft, would be $10 \times 3 \times 5{,}280 \times 450 = 71{,}180{,}000$. The draft per second, if 28 days be allowed for the total storage discharge, is 70.6 cubic feet, which at an average head of 45 feet equals 300 horse-power additional, derived from storage. Its additional cost is $90,000 — $35,000=$55,000, or $183.00 per horse-power, which is an excessive cost. Therefore in this case it would be best, from a financial standpoint, to develop with the small dam and long canal. Certain conditions might alter this conclusion. If, for instance, the stream flows through flat country, and the lake, formed by the lower dam, were extremely wide, so that the amount of storage would be greatly in excess of the above figures, the cost per horse-power would be correspondingly reduced, and one of the higher cost developments would be the advisable one. Also, if the extreme low water during the dry season should last only 14 days, the draft per second, and the resulting power, would be increased in the ratio of 28 to 14. This would reduce the cost per horse-power from $133 to $66.50 in the first instance, and from $183 to $91.50 in the second, both of which figures are admissible. Obviously these questions can be settled only by having a complete survey made of the property, and a number of reliable observations of the stream flow obtained.

The question of carrying part of the load during low water by means of an auxiliary steam plant is also a subject for consideration in every prospective hydro-electric development.

Taking the conditions as given in the foregoing example, there

are 28 days in which a storage equal to 120 cu. ft. per second is required to make the normal power due to 300 cu. ft. per second continuous. At 50 feet head and 80 per cent. efficiency this corresponds to 545 H.P. This may be obtained by a steam plant costing approximately $18,000, if the plant be of a simple character. The cost of operating such a plant would be about $8 per diem for extra labor and about $28 per diem for fuel and extras, or a total of $36 per day. The cost of supplying this power for 28 days would therefore be $1,008, which represents a capitalization of $12,600 taken at 8 per cent. The equivalent cost then of a steam-assisted hydraulic plant, referred to water power only, as a basis, and considering the first development before discussed, is $35,000 + $18,000 + $12,600 = $65,600. Obviously this is the plant best adapted to the conditions since it is cheaper than development No. 3, costs but little more than development No. 2, and gives the full power of the plant the year round, which neither of the others will do.

The steam auxiliary allows a much larger development of a given water power than is usually obtainable in any other way. If the stream, before discussed as an example, supplied 500 cu. ft. per second at all times except about 40 days in the year, 400 cu. ft. except 30 days, 300 cu. ft. except 14 days, and 160 cu. ft. as a minimum, the power obtainable could be based on 500 cu. ft. per second, and with a proper-sized auxiliary steam plant, would be $\frac{500 \times 50 \times .80 \text{ per cent}}{8.8} = 2{,}275$ H.P. as against 1,362 H.P. when 300 cu. ft. per second are used. The steam plant must be large enough to furnish the power represented by the difference between 500 and 160 cu. ft. per second or 380 cu. ft. This, at 50 foot head, equals 1,738 H.P. The cost of the steam plant will be about $60,000.

It will be called on to furnish power as follows: 1,738 H.P. for 14 days. Power due to 200 cu. ft. of water per second = (500 − 300) for 16 days. This amounts to 910 H.P. Power due to 100 cu. ft. of water per second (500 − 400) for 10 days = 455 H.P.

| | | |
|---|---|---|
| The H.P.-days' total are: | (1,738 × 14) | = 24,300 |
| | 910 × 16 | = 14,550 |
| | 455 × 10 | = 4,550 |
| Total........................ | | 43,400 H.P. days. |

Taking the cost of fuel, oil, waste, etc., at 6 cents per H.P.-day and extra labor at $8 per day, the annual cost of operating the steam plant will be:

| | |
|---|---|
| 40 days' labor at $8................ | $320.00 |
| 43,000 H P.-days at 6 cts........... | 2,604.00 |
| | $2,924.00 |
| Depreciation on steam plant at 2* per cent. on $60,000 | 1,200.00 |
| Total cost of operation........... | $4,124.00 |

which is interest at 8 per cent. on a capitalization of about $52,000.

Adding together the actual cost together with the equivalent capitalization, the cost of the plant to obtain 1,700 H.P. additional is $112,000. This is $66 per H.P., which is a low cost and would warrant this character of development.

Of course, with change in any of the local conditions, these figures would undergo variation which might be so considerable as to change the result completely and make some other course advisable. The foregoing is all given simply to indicate the factors involved in determining the proper form of development and to show how engineers proceed in arriving at their conclusions. The main object always to be kept in mind is the production of the most dividends and making the development at the lowest possible cost.

*Taken at this figure because of the short period of plant operation during the year.

# CHAPTER II.

## DAMS.

BEFORE discussing the various types of dams and their relative merits it is necessary to investigate the forces acting to rupture or overturn them.

In determining the stability of dams it is essential to find the centre of gravity of the section. Following are a few simple rules.

For a section like Fig. 2 or any quadrilateral having two parallel sides, bisect the parallel sides and join the bisections with a line Thus bisect $A\ B$ at $Z$ and $C\ D$ at $W$ and join these points by the line $Z\ W$. Extend each of the parallel sides, one in one

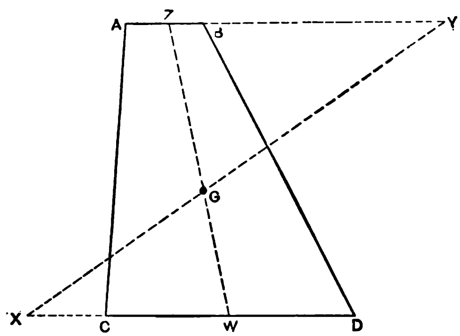



FIG. 2.

direction, the other in the opposite direction, the amount of the extension of each side being equal to the length of the opposite side. Join the ends of these extensions by a line. The intersection of this line with the line joining the bisected sides is the centre of gravity. Thus, $A\ B$ is extended to the right an amount equal to $C\ D$, while $C\ D$ is extended toward the left by an amount equal

to $A$ $B$. The line $Y$ $X$ joining the ends of these extensions intersects line $Z$ $W$ at $G$, which point is the centre of gravity.

The centre of gravity of a triangle is on the line joining the upper angle with the middle point of the base and is one-third the

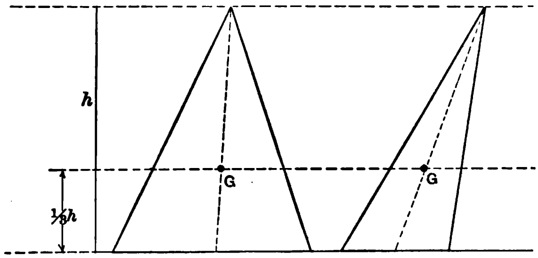



FIG. 3.

altitude of the triangle upward from the base. Fig. 3 indicates the location of the centre of gravity of triangular sections.

The centre of gravity of a figure like that shown in Fig. 4 may be obtained by dividing it into two parts such as $A$ $B$ $E$ $K$ and find-

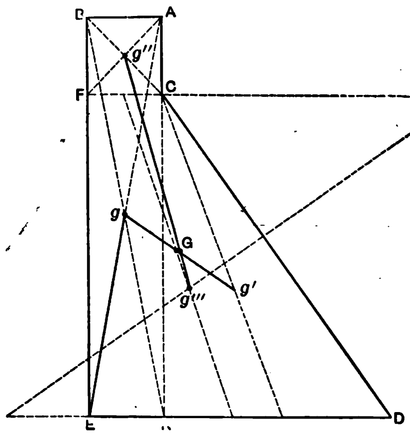



FIG. 4.

ing its centre of gravity as at $g$ and $C$ $K$ $D$ and finding its, as at $g'$. The centre of gravity of the figure is on the line joining these

two separate centres. Then re-divide the figure into two other forms such as $A\ B\ F\ C$ and $F\ C\ E\ D$. Take their respective centres of gravity at $g''$ and $g'''$ and join them by a line. The intersection $G$ of the two lines joining the two sets of centres of gravity is the centre of gravity of the figure.

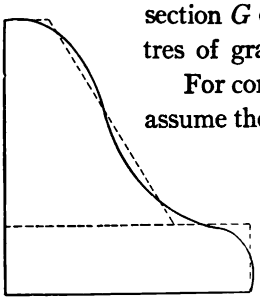


Fig. 5.

For contours like Fig. 5, it is sufficiently accurate to assume them to be as shown in the dotted lines, giving a quadrilateral with two parallel sides on a rectangle. The centre of gravity is easily found as above.

In Fig. 6 is indicated in outline the section through a dam with the water backed up behind it.

Consider one foot of length of the dam. The pressure of the water against the dam at the *bottom* is equal to the weight of one

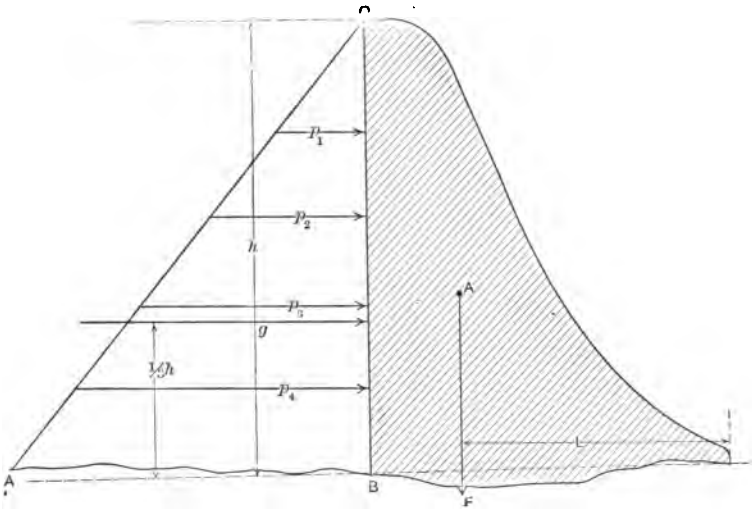



Fig. 6.

cubic foot of water multiplied by the depth in feet; *i.e.*, if $h =$ the depth in feet, the water pressure at the bottom of the dam, per foot length of dam, is $62.5 \times h$. To make this clear refer to Fig. 7.

Consider a dam with a depth of water behind it of 10 ft. Take a prism of water one foot wide measured along the length of the dam and one foot long measured back from the dam. This prism contains 10 cubic feet of water weighing $62.5 \times 10$ or 625 lbs.

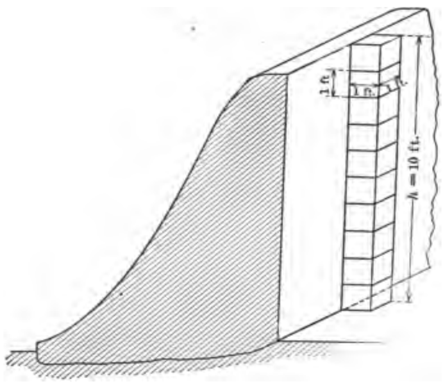



FIG. 7.

Its area of support at the bottom is one square foot. Therefore the pressure at the bottom is 625 lbs. per square foot, which is the same as $62.5 \times h$, when $h$=depth of water in feet. The depth of water at the top being zero, the pressure at the top is likewise zero. The *average* pressure per square foot of surface against the dam, tending to push it out of position, is the average of the top and bottom pressures, which is one-half the sum of the two. $0 + W h \div 2 = \frac{1}{2} W h$, is therefore the *average* pressure per square foot against the dam, W being the weight of a cubic foot of water.

The total pressure from top to bottom of the dam (per foot of horizontal length) is obviously equal to the average pressure per square foot multiplied by the height in feet; or is equal to $\frac{1}{2} W h \times h = \frac{W h^2}{2}$. The dam must therefore be amply strong for each foot length to resist the pressure equal to $\frac{62.5 h^2}{2}$ or, in metric

measurements, the pressure per metre length of the dam is 480 $h^2$ kilos when $h$ = depth in metres. This covers only the effect of the tendency of the water to push the dam down stream. As a matter of fact dams most often fail by overturning.

The forces involved here are not difficult to understand and may be easily understood by referring to Fig. 6.

The diagonal line $O\ A$ is the indicator of the horizontal pressure against the face of the dam at any depth of water. Thus, if the diagram be drawn to some convenient scale, so that the depth $h$ is equal to the number of feet depth of water and the distance $B\ A$ is equal to $62.5 \times h$ to the same or any other convenient scale, then the horizontal distance from the face line of the dam $O\ B$ to the diagonal $O\ A$ at any vertical point will be equal to the horizontal pressure against the surface of the dam at that depth. Thus $p^1, p^2, p^3, p^4$ are the different pressures at the various depths taken. Mathematically, the area of the triangle $O\ A\ B$ is equal to the total horizontal pressure of the water. The area of any triangle is equal to one half the product of its base by its altitude. In this case the base is W $h$ while the altitude is $h$, and half the product of these two is equal to $\frac{1}{2}$ W $h^2$ which is identical with the result previously arrived at in another manner.

Assume that the entire thrust of the water is concentrated at the centre of pressure which corresponds to the centre of gravity of the triangle $O\ A\ B$. The centre of gravity of any triangle is at one-third the vertical height of the triangle above the base. This point is indicated by $g$ in Fig. 6. The pressure to overturn the dam is $\frac{1}{2}$ W $h^2$ and it has a lever arm of $\frac{1}{3}$ $h$ through which it acts. The overturning moment therefore is the product of the force multiplied by its lever arm $= \frac{1}{2}$ W$^2$ $h \times \frac{1}{3} h = \frac{1}{6}$ W $h^3$. Substituting the value of W = 62.5 lbs., the formula becomes M = 10.4 $h^3$, M being the overturning moment of the water in pounds. In metric measurements this is equal to 160 $h^3$ kilos per metre length of dam where $h$ = depth of water in metres. To resist this overturning moment the weight of one foot length of the dam, multiplied by its lever arm of action, must be equal to or greater than M.

Call $w$ the weight per cubic foot of the material of which the dam is composed. Assume a contour or shape of the section of the dam and compute the area of this cross-section. The square feet cross-section are numerically equal to the cubic feet in one foot length of dam. If the cross-section of the dam is F. square feet, its weight per foot length will then be equal to $w$ F lbs.

Assume that this weight acts downward through the centre of gravity of the cross-section of the dam. It being still further assumed that when dams overturn they rotate about the rear lower edge or "toe," the lever arm through which the weight of the dam acts is the horizontal distance from the rear toe to the line of the centre of gravity. Call this distance L. Then $w$ F L is the moment of the weight of the dam to resist overturning, and this should be from three to four times as great as the moment of the water pressure acting to overturn it. This formula also holds if $w$ = weight per cubic metre, F = cross-section of dam in square metres and L = the lever arm of the centre of gravity of the dam in metres.

In Fig. 6, $A$ represents the location of the centre of gravity of the cross-section of the dam, and $F$ is its area in square feet, the weight per foot length of dam being $w$ $F$ as shown. $L$ is the horizontal distance from the toe of the dam to the line through the centre of gravity, and the moment to resist overturning is $w$ $F$ $L$ as shown.

It is not sufficient, however, to consider only the moment of the entire cross-section of the dam about the toe.

Fig. 8 shows the necessity for additional computations.

In this figure, although the area $F$ is somewhat smaller than in Fig. 6, the lever arm $L$ is greater and the product $w$ $F$ $L$ is practically as great. The dam shown in Fig. 8, however, would fail by the overturning of some portion of the upper section.

To proportion a dam properly it, therefore, is necessary to make computations for several sections—not less than three and usually five. This is done by dividing the figure into the number of horizontal sections desired. Fig. 8 is divided into three sections as

shown, the first being from the top down to the line *CE*, the second from the top down to the line *O K*, and the third from top to bottom, including the entire structure. Considering now the first section, the overturning moment of the water is 10.4 $h_1^3$. $h_1$ being the depth of water down to line *C E*. Call the area of sec-

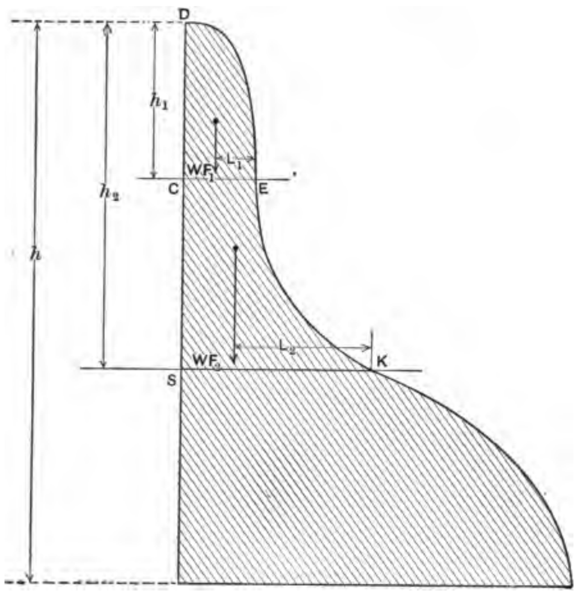



FIG. 8.

tion of the dam *D E C* included between the upper edge and the line *C F* equal to *F* and the horizontal distance between its centre of gravity and the rear face of the dam where C E intersects it equal to $L_1$, the weight per cubic foot of material being $w$, then the resistance of the upper section to overturning about the line C E is $w F_1 L_1$ and this must be three or four times as great as the overturning water pressure 10.4 $h_1^3$. Similarly the overturning water pressure about line S K is 10.4 $h_2^3$, $h_2$ being the depth of water down to line S K. The resistance to overturning is $w F_2 L_2$ in which $F_2$=area of section from the top down to line S K,

and $L_2$ is the horizontal distance of the centre of gravity of this section from the rear surface of the dam. In the same manner the total water pressure and resistance of whole dam are computed. All the computations should show the dam amply strong at every point. If any section taken shows too small a resisting moment the dam must be thickened at that section until the calculations show it to be safe. There are mathematical formulæ for computing the contour or form of the cross-section of a dam made of any given material, but the easiest, safest, and simplest way to lay out the cross-section is, by first assuming a shape

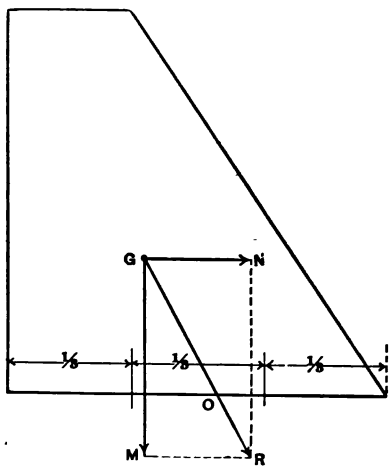



FIG. 9.

and then computing the relative overturning effects of the water, and the resistance of each of several sections of the dam as before indicated. By altering the different sections to correspond to the computed requirements, making thicker in some places and thinner in others, a proper form of cross-section can be obtained.

One of the general rules in designing dams is to take the resultant of the overturning force and the opposing stress, and note where this resultant intersects the bottom line of the dam. If the intersection falls within the middle third—*i.e.*, the middle one

of three equal lengths into which the bottom line of the dam contour is divided—the dam is considered safe. Thus in Fig. 9, *G* is the centre of gravity of the cross-section of the dam, and the downward vertical line *G M* passing through the centre of gravity represents to some scale the value of *w F* or the weight of the dam per foot length, while *G N*, also passing through the centre of gravity

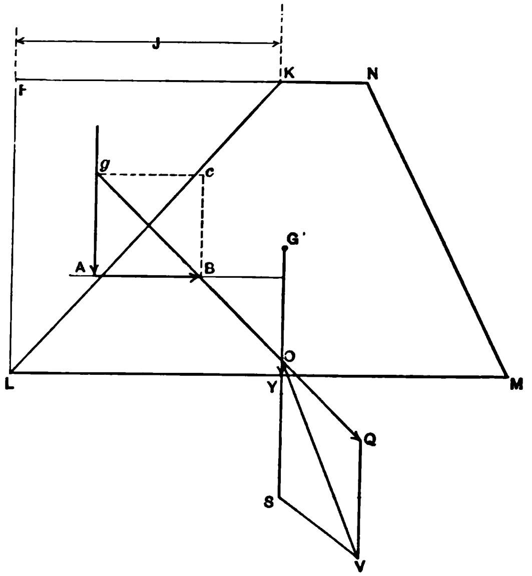



FIG. 10.

and at right angles to *G M*, represents to the same scale the value of the water pressure per foot length of dam$=10.4\ h^3$. Completing the parallelogram on *G M* and *G N* their resultant is *G R*, intersecting the base line at *O* which is well within the middle third.

This method of determining the stability of a dam is applied also to separate sections as previously described.

When dams are constructed with the up-stream face sloping, the stability is greatly increased, as the weight of the water tends to hold the dam against overturning. Thus in Fig. 10, if *K L M N*

be the contour of the dam, the centre of gravity, found by the construction before described, is at *G*.

The downward force acting at *G* due to the weight of the dam is *G Y*. *A B* is the horizontal pressure $= 10.4\ h^2$ acting horizontally at a distance of $\frac{1}{3}\ h$ above the bottom of the dam, while *g A* is the vertical pressure of the water $= \frac{1}{2}$ W J $h$ or $31.25 \times \text{J} \times h$ acting downward through the centre of gravity of the triangle *L F K* which represents the mass of water supported by the dam W being the weight per cubic foot of the water. The resultant of these two forces is found by completing the parallelogram *A B c g*. It is equal, algebraically, to

$$\sqrt{(10.4\ h^2)^2 + (31.25\ h\ \text{J})^2}$$

but it is easier to find this value graphically, which from the figure is equal to *g B* and has a direction perpendicular to *K L*.

To find the effect of this resultant force on the stability of the dam, combine it with the force due to the weight of the dam acting through the centre of gravity *G*, and equal to *G Y*. From point *O* where *G B* extended intersects *G Y*, extend *G Y* to *S*, *O S* being equal to *G Y*. Draw *S V* equal to *g B* and complete the parallelogram. The resultant is *O V*, which cuts the foot of the dam nearly underneath the centre of gravity and thus shows a large factor of safety.

In designing dams special care must be given to three important factors which are:—

(1) The spillway—*i.e.*, that portion of the dam over which the excess water pours—must be sufficiently long to pass over it all the water in time of heaviest flood, without the water rising too high in flowing over it. For this reason it is not always best to locate a dam in the narrowest part of a stream, as the spillway might be too short if the stream were subject to heavy floods. Whether a dam can be made very short or not depends largely on the variation in flow during the year and particularly on the maximum flow.

(2) The dam in every case, no matter how constructed or of what material, must rest on a solid foundation. All earth,

sand, loose rock, and other removable materials on the river bottom should be removed and the river bottom excavated until rock or hard-pan is reached. Too much care cannot be exercised in this matter. Usually after reaching rock bottom a shallow channel should be blasted out in which the bottom of the dam may rest. Failure to provide proper foundation will result in failure of the dam, no matter how well it may be built otherwise.

(3) Proper provision must be made for preventing the falling water, which pours over the spillway, from washing out the foundation or eroding the dam itself. Usually the dam is constructed

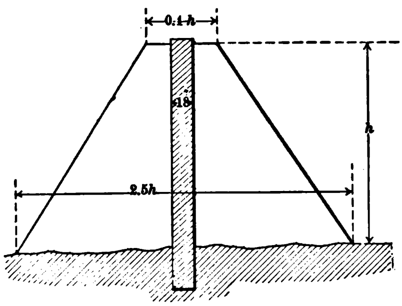



FIG. 11.

to carry the water down gently either on an incline or a curved surface, or in some kinds of timber dams the rear face is a series of short steps, so that the water falls easily from one level to the next.

There are several types of dams, and the construction adopted depends on the size, height, materials available, character of the stream bed, and the fluctuation in the stream flow. All these considerations are modified by the funds available and other commercial factors.

The dams in general use are: earthen, timber, masonry, and reinforced concrete.

*Earthen dams* are unsuited for any situations except for very low, short, deflecting dams where they serve merely to turn the

water into a canal or pipe. In no case can they be successfully used where the water ever passes over the crest. Their height should never exceed forty feet unless they are reinforced by an internal core wall of brick or masonry. If thus strengthened the height may be carried up to sixty feet.

Fig. 11 shows the general dimensions of an earthen dam having a masonry core.

If $h$=height of the dam, the thickness through at the toe or bottom should be 2.5 to 3.5 $h$, and the top thickness should be not less than 0.4 $h$. Thus for a dam 12 feet high, $h=12$. Thickness through at the bottom$=25 \times 12=30$ feet. Thickness at top$=0.4 \times 12=4.8$ feet=4 feet 10 inches. The thickness of masonry core walls should be approximately as follows:

| | |
|---|---|
| For dams up to 15 feet high | 18 inches |
| " " from 15 feet to 25 feet high | 24 " |
| " " " 25 " " 40 " " | 30 " |

The best material for earthen dams is a mixture of gravel and clay. Almost any proportions of mixture will make a good dam, though one-fourth clay to three-fourths gravel is a common proportion. Colonel Fanning recommends as a standard mixture the following, all proportions being by measurement:

| | |
|---|---|
| 100 parts | coarse gravel |
| 33 " | fine gravel |
| 15 " | sand |
| 20 " | clay |

*Timber dams* can be used in nearly any situation. They have the merit of being cheap, easy to build, and quickly put in place. They have the disadvantage, however, of requiring frequent repairs above the water-line. Of course those portions that are completely submerged will last indefinitely. They cost from one-third to five-eighths as much as a good masonry dam, depending on the locality. In many cases they serve the purpose admirably and enable a development to be made and put in commission where the expenditure would be prohibitive if a masonry dam were erected. Their forms are numerous, and could not all be here given in

proper detail, but nearly any engineer or constructor can design a wooden dam to resist the forces it may be subjected to.

Examples of timber dams are shown in Figs. 12 and 13. Fig. 12 shows a crib dam, made by piling up logs in square "cribs"

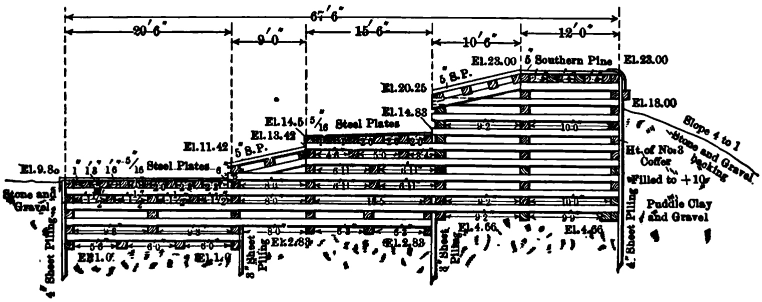



FIG. 12.

and filling these in with loose stone. The upper surface is covered with planking two inches thick, and the rear of the dam forms a succession of steps whereby the overflow water falls gently to the lower level of the tail race.

Fig. 13 shows another form of wooden dam, called a frame dam. The dimensions are given and the construction is obvious from the

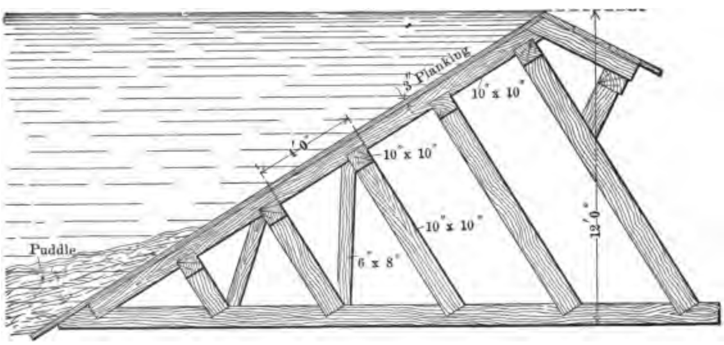



FIG. 13.

figure. The framework is filled with loose stone or gravel and covered over with planking.

In many instances where the maximum floods are small and

the river is wide, earthen dams are built nearly all the way across the stream and timber spillways fill the rest of the space, and thus a combination earth-and-timber dam is formed. The earth portion must be enough higher than the timber part to prevent water from ever passing over the former, all water flowing over the timber part only. The excess height of the earth dam above the tim-

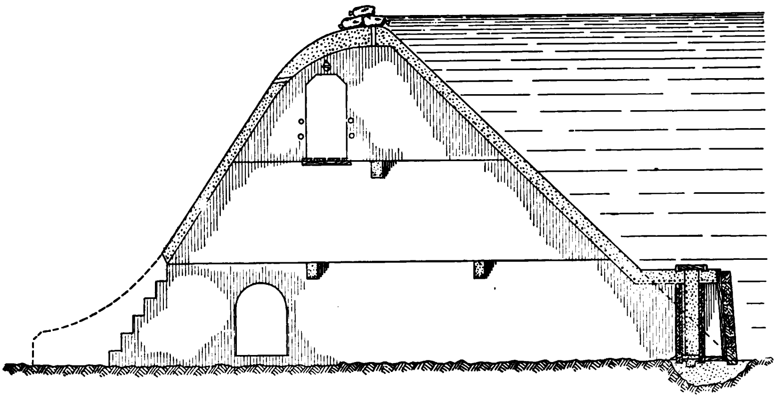


FIG. 14.

ber spillway depends, of course, on the length of the spillway and the maximum flow in time of flood.

*Masonry Dams.*—These are the most generally used, and, though the most expensive, are the most reliable and satisfactory, requiring a minimum amount for repairs and maintenance.

Fig. 6 shows the usual form of cross-section of a masonry dam. As will be seen, the rear face of the dam is curved in such a manner that the overflowing water follows smoothly down against the rear face, changing its direction continually and finally reaching the tail water without impact. The two curves which are reversed to each other, and which outline the shape of the rear wall, are parabolas.

Masonry dams have their approximate contours computed as before outlined in this chapter, and the smooth curves are drawn to adhere as closely as possible to the computed outline.

The materials used in dams of this type are widely variable. Some are made of cut stone, laid up in hydraulic-cement mortar.

A usual construction is to lay up the front and rear walls of cut stone, and fill in between these with concrete.

Cyclopean masonry is also used in some instances. This is made up of rough stones of various sizes and shapes, ranging from the size of a barrel down to the size of a man's fist. The smaller stones fill the interstices between the greater stones, all being laid in Portland-cement mortar.

Some dams are now made altogether of concrete, which is firmly rammed, as the construction proceeds, to solidify the mass.

FIG. 15.

More recently the growing use of steel-reinforced concrete has extended to hydraulic work, and the dams are strengthened by the use of reinforcing steel forms. These concrete dams are of the so-called "gravity" type. That is, they have a sloping face on the upstream side, and use the downward thrust of the water to give stability to the structure. In this way the weight of the dam may be greatly diminished and the cost proportionally decreased. Fig. 14 shows a section through a dam of this character. As may

be seen, it is hollow and depends for its effectiveness on the weight of the water rather than the absolute weight of the dam itself.

Fig. 15 is a masonry dam in the course of construction, its general form being that indicated in Fig. 6. Fig. 16 is a picture of this dam completed, with water pouring over the spillway. The effect of the curved rear face in carrying the water smoothly down is seen.

Dams must always be constructed with drain gates near the

FIG. 16.

bottom, so that, in case of repairs being necessary, the water may be drawn down and the entire reservoir drained. Usually these gates slide upward to open, being moved by a rack and pinion or, in some instances, a screw.

A drain gate should also be provided near the top of the dam, to allow accumulated trash and floating débris to pass through whenever this upper gate is opened. This gate also helps to discharge water in time of heavy flood.

# CHAPTER III.

## Canals and Flumes.

When the location of a dam is decided on, if it be at the foot of the fall or shoals, the power-house too will be located there, and no conducting of water will be necessary. If, however, the dam is placed some distance above the foot of the shoals, the water must be conducted to the power-house, which is always at the foot of the fall. The oldest method of carrying the water is by means

Fig. 17.

of a level canal running along the hillside until the power house is reached, and then being carried down through a pipe to the water wheels. Where necessary for the canal to cross gulleys, ravines, or other depressions, the crossing is made by means of a trough or flume supported on a trestle-work. Fig. 17 shows a wooden flume carrying water across a depression. Except under unusual conditions, however, it is better and cheaper to use pipe to convey the water to the power-house. The pipe does not have to be laid level, but can follow the contour of the shortest route from the dam to the power-house. For small powers, cast-iron

pipe is sometimes used; for large quantities of water, wrought-iron pipe is employed, while for low head, wood stave pipe held together by iron bands is used.

In some cases that portion of the pipe near the dam and where the pressure is low—say up to forty feet head—is made of wood stave pipe, while the lower portion of the conduit is made of riveted wrought-iron pipe, which gradually increases in thickness as the pipe sinks further and further below the reservoir level, that is, as

FIG. 18.

the pressure on the pipe increases, the strength of the pipe is increased.

Fig. 18 shows a wood stave pipe which forms the upper or low-pressure portion of a water conduit for a power station in the Western States.

Riveted wrought-iron pipe costs about double that of wood stave pipe. Following is a table of approximate costs *per foot* of riveted pipe of various diameters, to withstand pressure due to 250 foot head.

These costs change with increase or decrease of head. The figures are based on a unit price of $4\frac{1}{2}$ cents per lb. To compute the weight of any pipe take the circumference $\times$ length. This gives the area in square feet. Multiply the area by 2.5 and this

product by the number of 16ths of an inch thickness of the plate. Add to this 10 per cent. for lap and rivets. Thus a pipe 60 inches in diameter and $\frac{5}{16}$ inches thick weighs per 100 feet: $100 \times 3.1416 \times \frac{60}{12} \times 2.5 \times 5 = 11{,}881$ lbs. Add 10 per cent. and the total weight becomes 13,069 lbs.

TABLE No. 2.—COSTS OF STEEL PIPE.

| Inches | | Inches | |
|---|---|---|---|
| 10 | $ .72 | 24 | $2.35 |
| 12 | .82 | 26 | 2.60 |
| 14 | .98 | 28 | 3.00 |
| 16 | 1.20 | 30 | 3.15 |
| 18 | 1.40 | 36 | 5.00 |
| 20 | 2.00 | 40 | 6.40 |
| 22 | 2.25 | 42 | 7.00 |

The transmission of water through pipes is accompanied by a loss of head and this loss means that, for a given quantity of water, less power is available at the water wheels. The larger the pipe the less is the loss of head, but the greater is the cost of the pipe. Therefore, this feature brings in another commercial factor as to the size of pipe which represents the smallest loss of power and interest on the invested capital. Where the power is small and its value high, more money can be invested in pipe than where the power is great and its value low. The average size of pipe adopted in the United States is that which gives a velocity of water of from 4 to 6 feet, or from 1½ to 2 metres per second. Velocities as low as two feet (0.6 metre) and as high as 12 feet (3.6 metres) per second are known, but the figures given represent fair average practice.

If Q = quantity of water in cubic feet required per second for a given turbine under a specified head, the diameter of the pipe required with a given velocity is $D = 1.137\sqrt{\frac{Q}{V}}$ in which Q = quantity of water flowing in cubic feet per second, V = velocity of flow in feet per second. This formula also holds for metric measurements. If D = diameter of pipe in metres, Q = cubic metres of water per second, and V = velocity in metres per second.

The loss of head is computed from the formula

$$h=\left(\frac{f\,l\,V^2}{16d}+0.0234\ V^2\right),$$

in which

$h$=loss of head in feet;

$f$=a variable factor depending for its value on the character of the pipe surface;

$l$=length of pipe in feet;

$d$=diameter of pipe in feet;

V=velocity of flow of water in feet per second.

Values of $f$ are as follows:

For smooth-planed wood-stave pipe $=0.005\left(1+\frac{1}{12d}\right)$;

For smooth-steel plate pipe $=0.0065\left(1+\frac{1}{12d}\right)$;

For old and pitted steel pipe $=0.01\left(1+\frac{1}{12d}\right)$.

In arriving at the actual head acting on the water wheels the frictional head loss, computed as above, must be deducted from the total head to obtain the net effective head.

Where an open canal is used to convey the water to the power station, it is often practicable to make the side next the stream assist the spillway by constructing it to allow water to flow over the edge without injury to the canal bank. In such cases very short dams may be used, the length of spillway being made sufficiently great by using the side of the canal.

At the point where a canal joins the dam and the inflowing water enters, it should be protected against both heavy and light trash which floats down stream and accumulates. Stop logs placed out a few feet from the canal mouth serve to arrest the entrance of heavy timbers or branches of trees. These stop logs are simply booms made of heavy wooden timbers laid across the stream, which float on the water, but are anchored to prevent them from

moving from their positions. Trash racks must be put in place to stop the smaller and lighter trash, such as twigs, and particularly dead leaves. These trash racks are made of flat rectangular bars of iron or wood—preferably the former—which are put in an almost vertical position with the narrow edge to the inflowing water, each bar extending from a point four or five feet below the surface of the water to about five feet above it. The bars are spaced from 1 to 2 inches (2½ to 5 cent metres) apart and are fastened together to form sections, each section being from 2 to 3 feet wide. These sections, which are in effect vertical gratings, are held by a framework which is generally arranged with slides, so that each section may be hoisted up and cleaned when necessary, and afterward slipped back into place.

Forebays should also be provided. These are simply quiet ponds which are made by running low walls out into the water from the mouth of the canal, the walls spreading further and further apart as they extend outward. It is also customary to provide a forebay at the lower end of the canal, made by widening out the canal to three or four times its normal width, just at the power-house. The length of the forebay is about the same as its width. Its object is to allow the water to enter the water wheels smoothly and easily without eddy swirls; and it is simply a basin of sufficient volume to allow the incoming water, moving at some velocity, to settle quietly before going to the water wheels.

A second trash rack should be placed at the power station between the forebay and the entrance for the water to the turbines.

When closed pipes are used, a forebay, trash racks, and stop-logs must be provided at the mouth of the pipe, but none, of course, at the power station. In addition, provision must be made to prevent injury and possibly rupture of the pipes from water hammer, which occurs when the turbine gates tend to close too quickly unless some preventive measure is taken.

There are two methods of preventing water hammer. One is by means of relief valves, which are simply spring pressure valves very similar to an ordinary pop safety valve for steam boilers.

These open when the pressure in the pipe increases. They must be of ample area. Generally several are used, located at the lower end of the pipe, and their combined areas should be equal to at least thirty per cent. of the area of the pipe.

The other method is the use of a standpipe. This is a vertical pipe connected with the main pipe at a point near the lower end of the latter. This standpipe is open at the top and therefore must be high enough to be on a level with the surface of the head water or slightly above it. If the pressure in the pipe is normal, the standpipe simply remains filled to the top. A sudden increase in pressure in the main pipe line, due to sudden closing of the turbine gate, will cause water to flow up through the standpipe and pour over the top, the main pipe pressure having risen above that, due to the head of water in the standpipe. The area of the standpipe should be not less than thirty per cent. of the area of the main pipe, and fifty per cent. is better.

Obviously, since a standpipe must be as high as the head of water available at the power station, it is suited only to use on low heads, say not above 60 feet. It must be well braced against swaying, securely fastened in place, and provision must be made to catch and carry away its overflow. The water from it falls through a considerable height and will quickly erode foundations, concrete work, and the like if allowed to fall against any such structures.

For the benefit of those who are interested in following further the question of pressures set up in pipes with rapid closing and opening of water gates, an abstract of a paper on this subject, presented before the American Institute of Electrical Engineers by the author, is inserted as an appendix to this text.

## CHAPTER IV.

### THE DESIGN OF HYDRO-ELECTRIC POWER-HOUSES.

THERE are three general classes of power-houses. The first is that which is located at some distance away from the dam and the water conducted to the power-house, the flow of water being from the front to the back of the house, passing transversely under it.

The second is that in which water is conducted to the power-house, passing through water wheels located outside the house,

FIG. 19.

the flow of water being alongside and parallel to one of the outer walls.

The third is that in which the power-house is located at the dam, the water passing through the water wheels and transversely under the house.

In the first and third types, the houses are built on a series

of arches of masonry or concrete running transversely under the floor and which are sprung from piers that, in turn, rest on the foundations below. Usually the piers extend transversely the whole width of the house.

The floor of the house is constructed on the arches, by filling in over them with masonry or concrete until a level surface is obtained.

In cold climates where there is liability of freezing, the wheels are placed inside the power-house, but in warmer latitudes they

FIG. 20.

are put outside, with the stuffing-box end only of the casing passing through the wall and flush with the inner face.

The turbines are supported on masonry or structural steel supports, or, when located outside the house, they sometimes rest on extensions of the arches which project beyond the wall of the house. The water passes through the wheels and is discharged through draft tubes to the tail water below which flows through the arches underneath the house, to the stream bed. When the turbines are placed inside the house they rest on the floor above the arches.

The customary design provides for an arch for each main turbine and one for two small exciter turbines. Figs. 19 and 20 show, generally, power-houses of these types.

Taking up the first-class and considering it more in detail it may be subdivided into two types, (a) one in which the turbines are direct-connected to the generators, and (b) that in which the turbines are belted or rope-connected to the generators. In the former case the turbines are set at such a level that their shaft centres coincide with the generator-shaft centres, and a flanged coupling connects the two shafts. The generators are usually

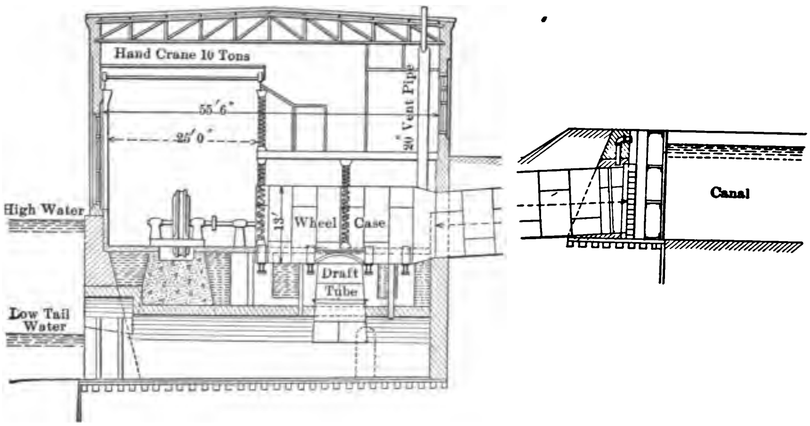



FIG. 21.

made with bases of such height that the distance from the masonry supporting floor to the centre of the generator shaft is the same as the height of centre of the turbine, so that the two rest on the same level.

When the turbines are set inside the house, the conducting tubes pass through the wall or under the archways and upward through the floor to the wheels. If the turbines are set outside the house, the stuffing-box end of the casing, through which the drive shaft passes, is set into the wall, the end of the casing being flush with the inner surface of the wall or possibly projecting a

few inches into the room. These remarks apply, of course, only to iron-shell-encased turbines.

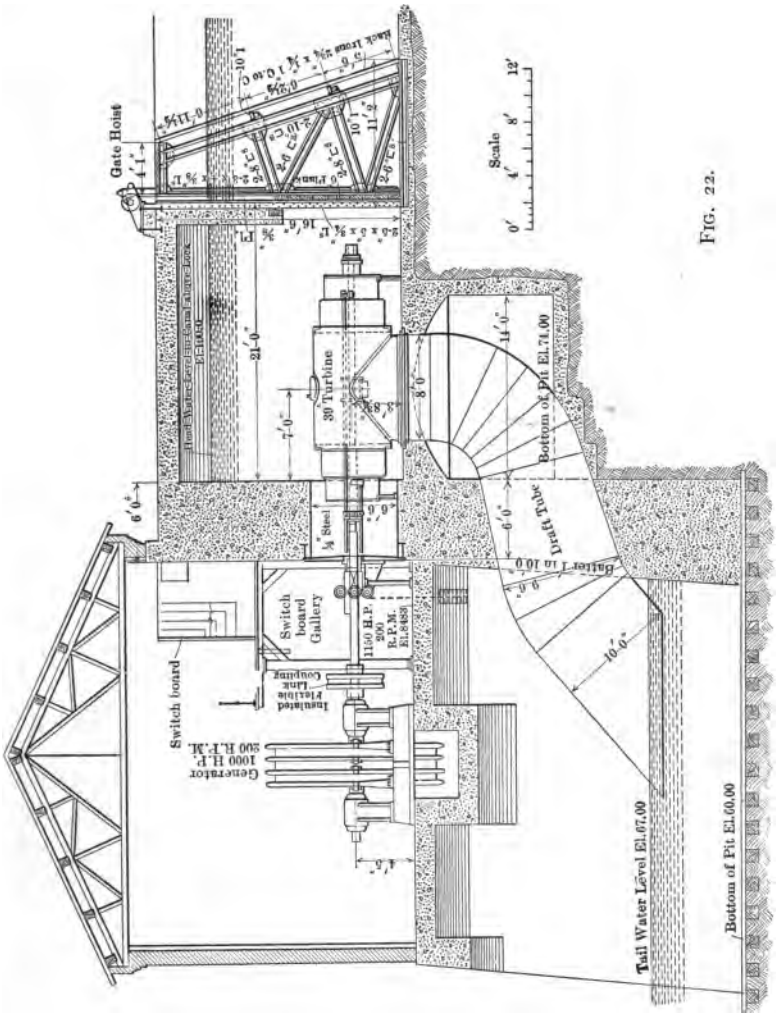


FIG. 22.

When the wheels are set in open penstocks of masonry or concrete, one wall of the power-house usually serves as a wall of the

penstock. Stuffing boxes fastened into the wall allow the turbine drive shafts to pass through into the power-house without leakage of water. Fig. 21 shows a cross-section through a station using an iron-encased turbine inside the house direct connected to the generator it drives. Fig. 22 shows a direct-connected plant in which the turbines are located outside the house in an open penstock. The supporting arches which carry the power-house floor are clearly indicated in these sections. As may be seen in

FIG. 23.

Fig. 21 the conducting pipe from the dam goes directly to and connects with the iron casing of the turbine.

The use of the open penstock is confined to low heads—say up to thirty-five feet—and generally, the water conduit is a canal or open flume which discharges into the penstock, though in some instances pipes conduct the water to the penstock. Whenever it is feasible, the open penstock should be used, as the regulation obtainable on the water-wheels is improved and they are more accessible for inspection and repair.

Some plants have the water supplied by a canal which ends in a forebay near the power-house, and a short tube conducts the water to iron-encased wheels. Power-houses for such equipments are similar to the arrangement shown in Fig. 21.

Power-houses of the second class, *i.e.*, where the discharge water

from the turbines does not pass under the house, but alongside of it, are usually for small-capacity plants. The house may be supported in any manner which seems most suitable for the particular situation, no provision being made for the passage of water underneath it. Fig. 23 is a view of a plant of this type. The turbines are supported on a masonry foundation extended upward

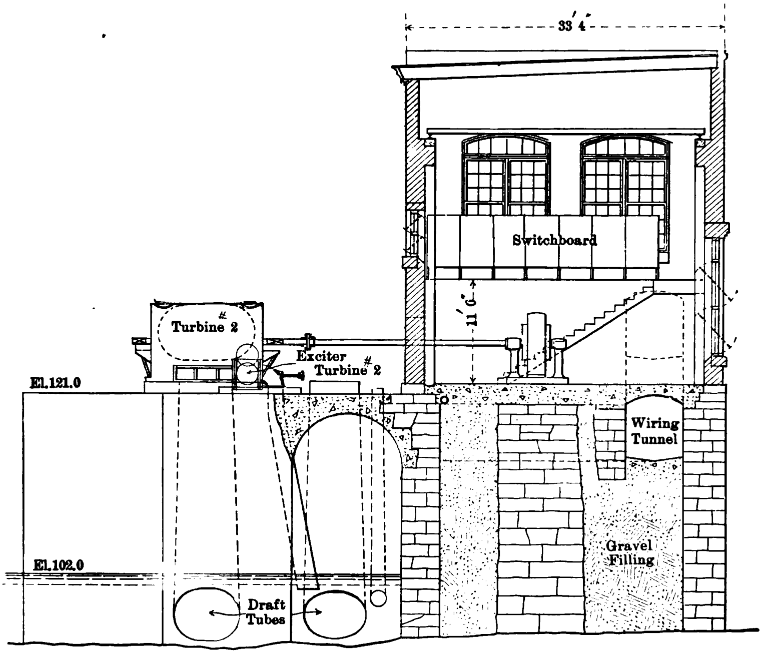



FIG. 24.

until its surface is approximately level with the power-house floor. An archway in the water-wheel foundation provides for the discharge of water.

Fig. 24 is a cross-section of this plant, showing the building walls and the supporting piers for the generators, running down to bedrock.

For small plants in warm or temperate climates this is an excellent and low-priced form of construction.

The most general construction at present in favor is to build the power station at the dam, when possible, and to let one wall of the power-house be close to the dam, and in some cases the rear of the dam forms one wall of the house. This portion of the dam is not made in the same form as the rest, but rises much higher than the crest of the spillway portion and is simply shaped to give the requisite resisting strength, not curved to carry away overflow, since there is no passage of water over this portion of the dam; in fact, the added height is for the purpose of preventing any overflow at that end. This raised portion is called the bulkhead.

The turbines used in such cases are almost invariably iron-encased, their shells being extended to pass through the bulkhead and receive the water direct without the necessity of using conducting pipes of any kind.

When the bulkhead serves as the power-house wall, the turbines are placed inside the house, their casing extensions passing through the bulkhead and being sealed into the masonry. The turbine end of the casing being inside the power-house, the wheels themselves are accessible for repairs.

In some of the later plants the power-house wall is separated from the bulkhead, there being a short space between the two. The turbine casing passes through bulkhead and across the intervening space and through the wall of the house, ending just inside the wall or flush with it at one end, and at the inner bulkhead face on the other. Large openings are made in the casing, between the bulkhead and house wall, and through these openings the wheels may be inspected and repaired. They are closed up with steel plates bolted in place.

The draft tubes pass down through the supporting arches—which are extended up to the bulkhead and joined to it—and the water is discharged below the floor passing under it, just as has been before described.

Fig. 25 illustrates this method of construction. The level of the water shows the height of the spillway portion of the dam, and, as may be seen, the bulkhead portion is much higher than the crest

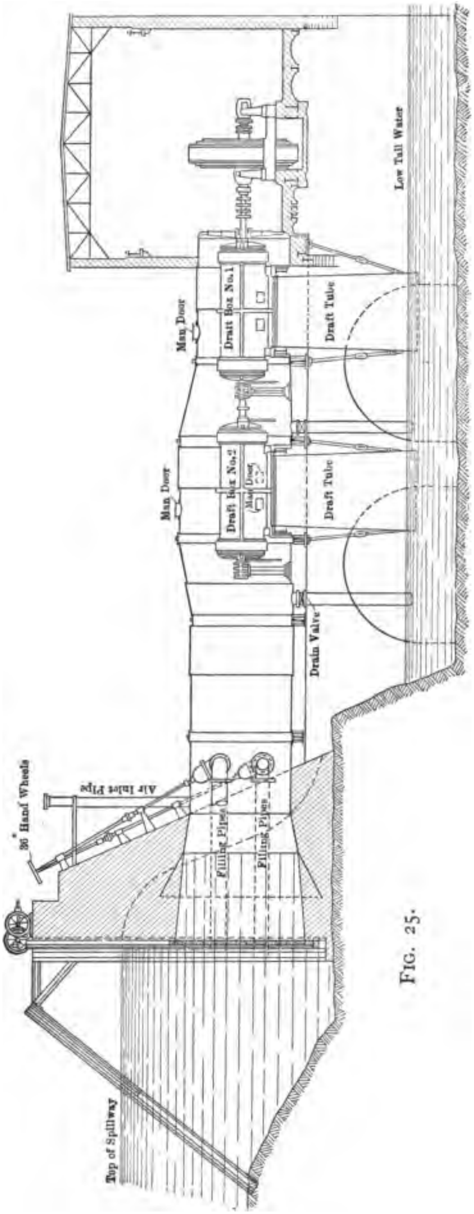

Low Tail Water
Man Door
Draft Box No.1
Draft Tube
Man Door
Draft Box No.2
Man Door
Draft Tube
Drain Valve
36" Hand Wheels
Air Inlet Pipe
Filling Pipes
Filling Pipes
Top of Spillway

FIG. 25.

of the dam. The turbine units, in this case, comprise two pairs of double wheels coupled tandem.

In many instances, the low speed of the turbines due to low heads precludes the possibility of using low-priced dynamos if direct connected to the turbines, owing to their similarly low speeds. It therefore becomes necessary to drive the dynamos by belting or rope drives from the turbines, in order to give a higher speed to the generators than that of the turbines. In such plants it is customary to make the station floor considerably higher than the level on which the turbines rest, generally from ten to twenty feet higher, and have the belts or ropes pass diagonally upward from the turbine drive pulley to that of the dynamo. The turbines may be placed outside or inside the house and may be in open penstocks or steel-encased. Usually in such cases, however, the water-wheels are installed in open penstocks outside the house, and their drive shafts extend through stuffing boxes into the house walls. On the inner ends of the shafts are placed the drive wheels which transmit the power to the dynamos.

When the hydraulic heads are very high, impulse wheels of the Pelton pattern are used, and these rotate at very high speeds. The impact of the water jet coming from the supply nozzles is so great that provision must be made to prevent the erosion of power-house foundations and consequent collapse of the structure. This is done by providing a deep, long pool of water against the surface of which the deflected portion of the jet strikes. At the far end of the pool is a baffle which maintains the required depth of water in the pool, usually from five to eight feet. The impact of the water from the nozzle being at an acute angle to the pool water surface, the jet passes a considerable distance, diagonally, before striking the bottom of the pool, and its velocity has practically been reduced to zero by the time the bottom is reached, so that there is no scouring or erosive action.

Fig. 26 shows a section through a power-house of this character. The arrangement of impulse wheel and nozzle is clearly indicated.

In designing power-houses care must be taken to locate the

water-wheels at a proper height above the tail-water level. Where streams are reasonably constant in their volume of flow and the tail-water level does not vary greatly, the turbines should be placed at a height of from 8 to 12 feet—or $2\frac{1}{2}$ to $3\frac{1}{2}$ metres—above the normal level of the tail water, the distance being measured from the centre line of the turbine. In cases, however, where the flow of the stream fluctuates greatly, the tail-water level will also vary within wide limits and the turbines must be placed higher. The

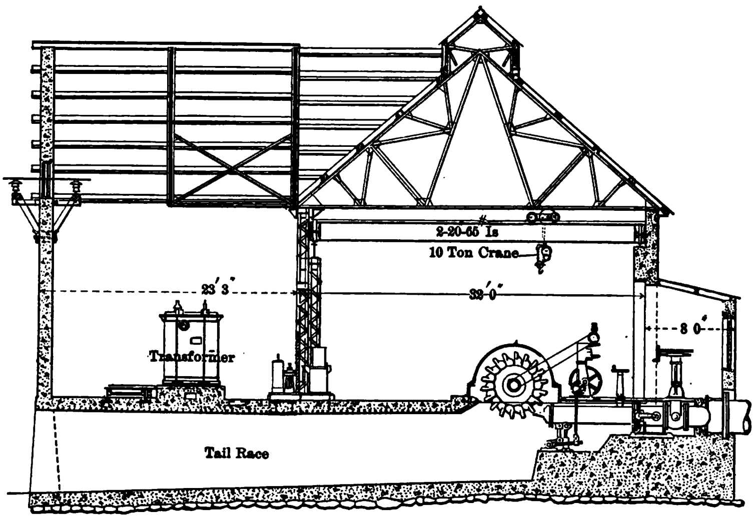



FIG. 26.

conditions in this respect, have, in some instances, required the turbines to be located twenty feet above the normal tail-water level. The efficiency of the draft tube begins to decrease if its length exceeds fifteen feet, and in no case should turbines be placed more than this height above normal tail-water level unless the conditions absolutely require a greater height.

Power-houses are built of a variety of materials. The construction most in favor in the United States is the masonry or concrete for arches, piers, and foundations, brick for the structure it-

self, reinforced concrete for floors, and a trussed roof of structural steel, covered with slate, tiles, or gravel roofing. Iron or steel roofing is not suitable for power-houses because it "sweats" or accumulates condensed atmospheric moisture on the under surface. Whatever be the method of construction, the station should be made entirely of fire-proof material.

The floor space of the station should be sufficiently large to admit of getting at every side and part of each machine, with plenty of space between machines and walls or between neighboring machines to easily pass round them and to remove any part with ease and facility.

The height of stations varies greatly. The minimum height from floor to roof trusses should not be less than 18 feet, but in very small plants this has been made as low as 16 feet. For moderate-size stations, 20 to 22 feet is a fair height, while 26 to 28 feet is usual in large stations where the dimensions of the generators are considerable.

The foundations should, when possible, rest on bed-rock. When this is impracticable or if hard-pan cannot be reached, it is necessary to drive piles, cut them off below the low-water level so that no portion of them may ever become dry, and put in a concrete footing on top of the piles. The number, length, and size of the piles depend on the character of the soil and the load to be carried. The usual spacing of piles is three feet between centres, though this is frequently varied to suit conditions. No general instructions can be given for this part of the work, as each case must be treated to cover the individual conditions that exist.

Nearly every station is designed to carry overhead travelling cranes, by means of which the machinery may be erected and any part easily and quickly lifted out of place for inspection and repairs. This is a desirable arrangement for large stations having many units, but, in the opinion of the author, it has been carried too far in the design of small stations. A good travelling crane with its runway and supporting structure is expensive, and in many cases the money spent therefor could be used to better advantage

in providing higher grade generating equipment, or letting it remain unspent. A heavy set of short, strong shear legs, arranged in tripod form, with a differential chain hoist, is all that is required in small power-houses.

The switchboard should be located on a gallery elevated above the floor level. The heights that are usual are from seven to ten feet. Underneath the rear of the gallery are placed brick chambers in which are located the high-tension switches, operated directly from the switchboard above.

When transformers are used, they are generally located in the power station itself, though in some recent plants a separate building is provided for their reception. Each transformer should be placed in a separate brick or concrete chamber, well ventilated and provided with a fire-proof steel door at the front. The floor level of the transformer chambers should be the same as that of the station floor so that any transformer may be rolled out on the rollers placed under each one onto the station floor for inspection or repair.

One of the important factors in hydraulic-power plant design is the proper provision for removal of sand, leaves, ice, and trash from the water flowing into the wheels. Sand is detrimental owing to its cutting action on the water-wheel blades; and in high-head plants, where impulse wheels are used and the velocity of the water is high, a very slight amount of sand will quickly cut through the wheel bucket. The usual way of removing sand is to provide a settling basin at the upper end of the pipe, where the water comes to rest and stands long enough to let the sand settle to the bottom of the basin.

Surface or floating ice gives but little difficulty if the conducting pipe is set into a forebay or basin, several feet below the surface of the water, as the ice simply covers the basin, and the water flows to the pipe beneath it. The so-called frazil ice, however—*i.e.*, ice in finely divided form—mixes with the water and is held in suspension and it will, therefore, pass through the pipes to the turbines and clog them, no matter how far below the surface of the water

the pipe may be placed. A large forebay or settling basin at the power-house is required to prevent the inflow of this frazil ice. It slowly floats upward, freezing solid at the surface, and in this way the water is cleared.

Accumulations of leaves are particularly troublesome, and it is difficult to clear the water of them. Trash racks, such as described in the foregoing chapter, will prevent them from getting to the wheels, but the racks themselves become clogged and require continual cleaning; in some cases two men are kept busy continuously clearing the racks.

Specially designed forms of moving-chain conveyors which allow the water to pass through them, but catch and elevate the leaves, discharging them onto a platform or to one side of the flume, have been used with success. There is no standard device, however, for this purpose, and each case must have the design made to suit the individual conditions.

# CHAPTER V.

## Water-Wheels.

Water-wheels may be divided into three classes, viz., pressure turbines, impulse turbines, and Pelton or jet wheels.

The pressure turbine consists of a rotating wheel having curved vanes or buckets attached to its periphery, and stationary vanes which serve to direct the flow of water into the wheel buckets. The forms of the guide vanes and the wheel buckets are such that the water enters the openings without appreciable impact, but guided in a particular direction and having a certain velocity of flow. The wheel buckets change the direction of flow of the water, and it is this reaction, due to changing the direction of motion of the mass of water, that produces the turning effort on the wheel. There are many designs for forms of buckets, and most of the successful ones have curvatures in two planes so that the water is received at the level of one plane and rejected at a lower plane, its direction of motion continuously changing throughout its path through the wheel buckets.

The wheel and guide buckets may be in the same plane, the stationary guide buckets being inside the periphery of the wheel, the water being received through a central opening and discharging radially outward. This type is termed the outward-flow turbine. If the guide vanes are placed above the wheel so that the direction of flow of the water is parallel to the wheel axis and perpendicular to the wheel, it is called a parallel-flow turbine. The inward-flow turbine has its guide buckets outside of and surrounding the wheel, the water passing inwardly and radially toward the axis. A very successful form of wheel or runner is shown in Fig. 27, which is the type of wheel most largely used

in the United States. It combines the features of inward and parallel flow, the water passing to the wheel inwardly and radially, and being discharged from it downwardly and parallel to the wheel shaft.

FIG. 27.

Any of these wheels may be set with their axes either horizontal or vertical, provided a depth of not less than six feet of water is obtainable above the upper surface of the wheel when set horizontally. It is customary to employ vertical wheels for heads of less than twenty feet, although horizontal wheels have been placed and successfully operated under heads as low as fourteen feet.

With pressure turbines it is not necessary to set the turbine down at the level of the tail water in order to get the full effect of the total head. As before mentioned in describing power-house construction, pressure turbines may be set anywhere from two to twenty feet above the level on the tail water if an air-tight draft tube, leading from the wheel discharge down below the level of the tail water, be provided. This is due to the fact that the submerged end of the tube is sealed, and the falling water in the tube from the turbine discharge tends to create a vacuum in the draft tube, which has the effect of sucking the water through the turbine and adding a pressure to the inflowing water proportional to the vertical height of the draft tube.

The usual speed of pressure turbines is such as to give a peripheral velocity of the wheel equal to approximately three-fourths of the spouting velocity of the water under the head applied. Recently, however, certain high-speed turbines have been produced in which the peripheral speed of the wheel is equal to 90 to 95 per cent. of the spouting velocity of the water. The spouting velocity in feet per second is equal to $8\sqrt{\text{Head in feet}}$.

The variation in the power of the wheel, under a given head,

for variations in load is effected by varying the amount of water admitted to the guide buckets or to the wheel buckets. There are three types of variable gates, viz., the cylinder, the wicket, and the register gate.

Cylinder gates are simply sheet-iron cylinders which surround the stationary guide buckets. These cylinders are movable in a direction parallel to the wheel axis. In one extreme position the openings to the guide vanes are completely covered; in the other extreme position they are completely uncovered. As the cylinder moves to different positions between these extremes, the areas of the openings are correspondingly varied.

The wicket gate is arranged as shown in Figs. 28 and 29.

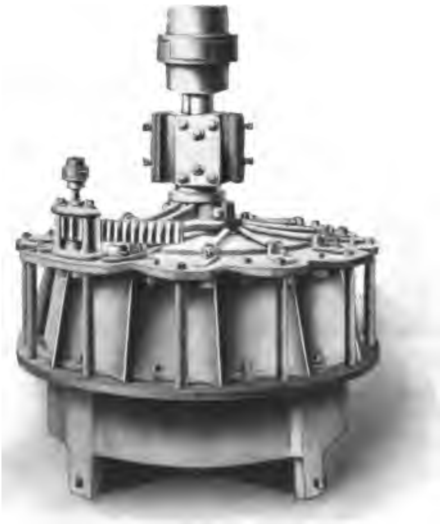


FIG. 28.

In Fig. 28 is shown the moving mechanism, while in Fig. 29 is shown a sectional plan. In this arrangement the guide vanes are pivoted so that they may have their positions shifted. Each vane pivot has a crank arm attached to it, and an iron rod is connected to each

of these cranks. The iron rods all have their ends attached to a flat central ring of iron. When this central ring is rotated through a small angle, the guide vanes are caused to approach toward or


FIG. 29.

recede from each other, thereby varying the area of the openings through the guide vanes.

The register gate is made of an iron cylinder surrounding the guide vanes and having a series of openings cut into it the size and form of which correspond to the size and form of the openings between the guide vanes. In the position where the openings in the cylinder correspond exactly with those between the guide vanes, the full flow of water passes to the wheel. If, however, the cylinder be rotated through a small angle so that the position of the openings in it does not correspond with the position of the openings between the guide vanes, the latter will be closed up either partially or wholly, depending on the amount of rotation of the

cylinder, and thereby the flow of water to the wheel may be varied as may be desired from zero to a maximum.

Of these gates the wicket gate is most used and is probably the most satisfactory, especially when the gates are to be controlled by an automatic governor. The cylinder gate is also a good form of gate for automatic governing. The register gate is not to be recommended except when the water is free from sand and grit and the governing is to be done by hand, as it is subject to rapid wear in gritty water, and the friction between it and the guide-vane structure is too great to admit of rapid movement with ease.

There are two methods of supplying water to pressure turbines; one is to set the wheel in a large chamber, open at the top, which communicates with the head water and is filled up to practically the same level as the head water, completely submerging the wheel. The discharge water is taken from the wheel through the draft tube, which passes through the bottom of the chamber and is sealed in the bottom so that none of the water can pass from the chamber through this opening; the only possible path for the water being through the turbine and out by the draft tube. This is called an open-penstock setting. Where heads are low, say up to thirty feet, this is the best possible method of placing a turbine. Where the turbine is vertical, the shaft projects upwardly, rising above the surface of the water, and from its upper end power may be taken. When the turbine is set horizontally, the shaft passes through the side of the chamber, a water-tight stuffing box being placed around the shaft to prevent leakage. Fig. 30 shows the arrangement of a pair of horizontal turbines set in an open penstock, the shaft passing through the stuffing box in the side.

Penstocks may be made in any manner and of any material which will be water-tight. In some cases they take the form of large square wooden boxes. Usually, however, they are made of reinforced concrete. In every case they must be sufficiently strengthened and braced to resist the water pressure which tends to bulge the walls out and burst them apart. Where several turbines are installed, it is advisable to separate the penstock into as many

divisions as there are separate turbine units. Normally, the division walls will be subject to no bursting stresses, as the height of water is the same on either side, and the water pressure is thus

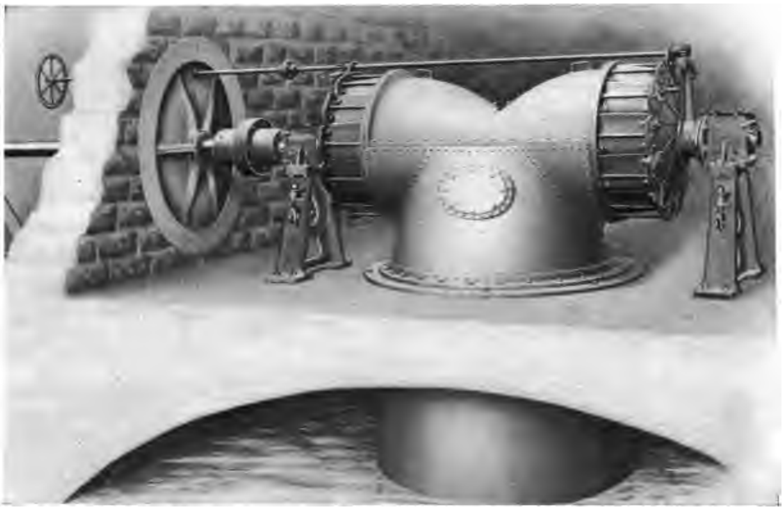


FIG. 30.

neutralized. If, however, it becomes necessary to inspect any particular turbine or make repairs on it, the water in this division of the penstock must be drawn off. This leaves the walls of the empty division subjected to the pressure of the water from the adjacent compartments, and it is therefore necessary to construct these division walls with the same strength as if they were separate penstocks.

The other method of setting pressure turbines is to enclose each unit in a steel casing, into which water is conducted by means of a pipe leading to the head water. The draft tube is taken out through the end of the casing or down through the bottom, depending on the form of water-wheel used. This method of installing has certain mechanical advantages. It is very convenient and occupies less space than does the open penstock, and

is the only suitable and commercial method for heads above thirty-five feet. The speed regulation and the efficiency attainable are, however, not as good as with the open-penstock setting.

The pressure of the water against the wheel is principally radial, but there is considerable pressure also exerted in a direction parallel to the wheel axis, and this requires that turbines be provided with thrust bearings to take this longitudinal pressure.

In order to neutralize this pressure and also to obtain high rotative speed under a given head, it is customary to place two water-wheels on a single shaft, each wheel having half the power that it is desired for the unit to supply. Since the longitudinal press-

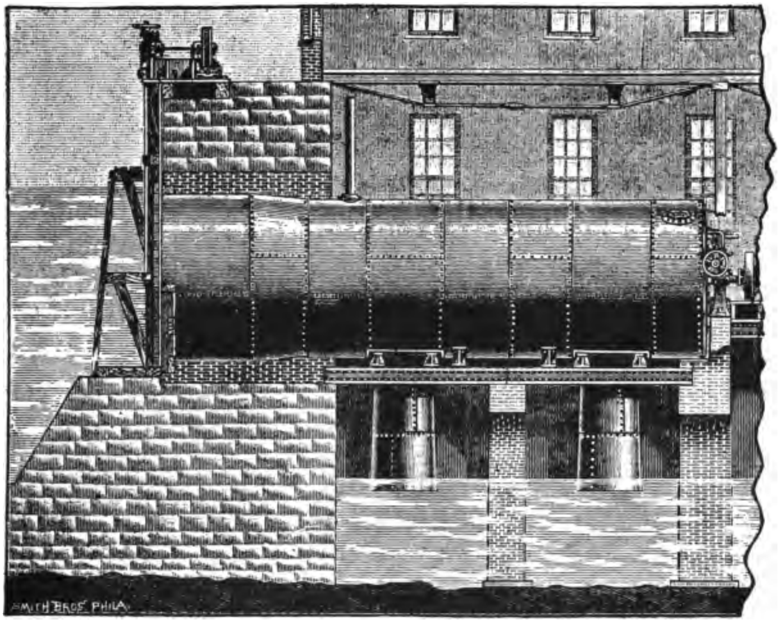



FIG. 31.

ures act in opposite directions, they neutralize as desired; and as each wheel gives only half the power required, its smaller size gives a higher rotative speed. When set in an open penstock,

these wheels are supported by a draft chest which rests on the bottom of the penstock and to which the draft tube is attached that takes the discharge from both wheels. Such a setting is shown in Fig. 30. Obviously, a pair of wheels with their draft chest instead of being set in the open penstock may be encased in a steel shell as indicated in Fig. 31.

In many cases where double units are encased in a cylindrical steel penstock, the water, instead of flowing from either end toward a common central draft chest, flows from the middle toward either end and discharges through two draft tubes as shown in Fig. 32. The large, ninety-degree elbows at either end of the casing are called "quarter turns," and in each is placed a stuffing box to allow the

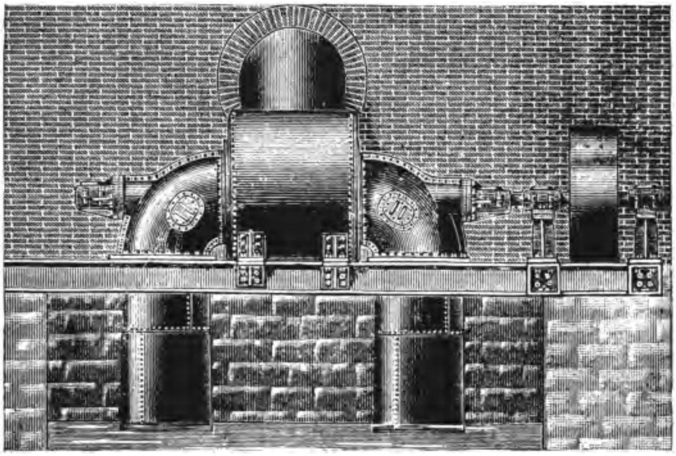


FIG. 32.

turbine shaft to pass through. This form possesses several advantages over the central-draft-chest arrangement. Its first cost is from 25 to 30 per cent. less than the cost of central-draft-chest turbines of the same power, its efficiency is from 2 to 5 per cent. greater, and it may be supported by piers or pillars directly under the turbine casing and wheels. Therefore this type should be used whenever possible.

The efficiency of pressure turbines when new and in good condition is about 80 per cent. at $\frac{7}{8}$ gate. This efficiency usually falls off at full gate and below $\frac{7}{8}$ gate. Also, in the course of time, the buckets become worn by the action of the water, grit, and other substances which are carried into the wheel, and both the power and efficiency are reduced. This is important and should be borne in mind when deciding on the size of wheel necessary for any given service. At least $12\frac{1}{2}$ per cent. excess capacity should be allowed to admit of good regulation under varying loads and to compensate for this reduction in power which takes place in the course of time.

Pressure turbines may be obtained in standard designs for heads up to 100 feet. Specially designed wheels for heads up to 160 feet are supplied by various makers. When heads are greater than 160 feet impulse turbines or impulse wheels should be used.

Draught tubes should be proportioned so that the velocity of the water in them is about five feet per second when the turbine is developing full power. When the velocity is less than two feet per second the vacuum is not so good as at somewhat higher velocities and where water-wheels are subjected to varying loads it is possible to get too low a velocity in the draught tube at one-third or one-half gate. Of course, if wheels are designed to run on steady loads, the velocity for full gate may be somewhat lower than the figure given, but in any case the loss of head in a draft tube even at velocity of 6 or 7 feet per second is practically negligible, and as a general all-round figure, 5 feet per second is about the best.

Draught tubes should taper and have a greater diameter at the bottom than at the top. The diameter at the bottom should be about 25 per cent. greater than the diameter at the top, and the velocity of 5 feet per second should be taken for the upper or small cross-section. The lower end of the tube should be submerged at least 8 inches and in large draught tubes—say 8 feet in diameter and above at the bottom—they should be submerged not less than 20 inches.

A difficulty that frequently confronts the designer of a plant is that of a low head greatly influenced by floods, where the tail water backs up in time of flood and materially reduces the effective head. Under these conditions there is an abundance of water available, and the water-wheels can work if necessary at a low efficiency. The power and speed must be maintained the same as when the normal head is acting.

Many complicated methods of involving gears, belts, and other devices have been suggested. It is the author's practice, however, to use extra turbine wheels or runners on the same shaft, sometimes fastened solidly on and sometimes connected or disconnected by means of a jaw clutch coupling. For instance, if the normal head is 36 feet, with a depth of 6 feet in the tail race, and the flood raises the depth in the tail race to 18 feet, making the net head 24 feet, there should be three horizontal turbines on a single shaft. Assume the power to be developed as 500 H.P. Then two of the turbines running at full gate should give approximately 575 H.P. under a 36-foot head, and at $\frac{7}{8}$ gate they will give 500 H.P. Under 24 feet head at full gate, they will give only 312 H.P. the power of a turbine being not proportional to the head but to the $\sqrt{\text{Head}^3}$. The third wheel, therefore, must give 188 H.P. under 24 feet head. When the head is normal this third wheel is idle, its gates are closed, and it merely rotates on the shaft with the other wheels.

The speed varies as the square root of the head. At 36 feet, if the speed is 280 r.p.m., at 24 feet head, it will tend to fall to 229 r.p.m. If the velocity of the wheel buckets is 75 per cent. of the velocity of the water at 36 feet head, and a 5 per cent. fall in speed at high water is allowable, the rotative speed of the wheel is 280 — 5 per cent. = 266 r.p.m, the peripheral velocity of the wheel will be about 84 per cent. of the velocity of the water when working under the lower head. The two main wheels therefore should work with their highest efficiency at $\frac{7}{8}$ gate with a peripheral velocity of 75 per cent. of the velocity of the water under 36 feet head $= .75 \times 8 \times \sqrt{36} = 36$ ft. per second; while they should be able to give ap-

proximately their full proportional power when running at 85 per cent. of the velocity of the water, and the third wheel should be proportioned to work under the lower head.

Sometimes the conditions are even worse than the above case, and it may become necessary to install two turbines on a single shaft, one of which gives the necessary power and speed at the normal head, the other giving the proper power and speed at the low head. The peripheral velocity of the smaller wheel for the high-head service may be greater than the velocity of the water at the low head, in which case the gates of this wheel must be completely shut at times of high water, as it not only would not assist the low-head wheel, but would be a drag on it, using up instead of giving out power.

Another method of arranging turbines to compensate for variation in head is to place two units in separate steel casings or penstocks, each having its pipe connection to head water and its draught tube, both wheels being on the same shaft. Additional pipe connections are made and valves put in at proper points, which allow the shutting off of one draught tube at the bottom and turning the water from the closed draught tube into the case of the adjacent turbine. A valve in the flume or pipe line leading to this second unit, cuts off the water from the source of supply. With both valves open each turbine receives water from the flume and discharges it through its draught-tube, and, both wheels being on the same shaft, the power delivered is equal to the combined power of the two wheels, under the available head. This is the operation at times of high water when the head is low and plenty of water is available. When there is but little water the valves are closed and the water then passes through the first turbine, into the second, and out through the draught tube of the second wheel. Obviously, the speed and power developed by these units under a 50 foot head with 200 cubic feet of water flowing per second will be the same as the speed and power under a head of 25 feet and a flow of 400 cubic feet per second. At intermediate stages of high water, between the normal and the maximum, partial closing

of the valves will allow corresponding adjustment of the units for the reduction in head and increase in the volume of water.

In some instances, owing to very low head or want of room, it becomes necessary to use vertical turbines. Any pressure turbine will work at its highest efficiency if set vertically. The difficulty, however, is in transmitting power to the dynamo which is usually

FIG. 33.

set horizontally. In the case of small units, this may be done by means of a quarter-turn belt or rope drive, but this is not feasible for dynamos of above 100 kilo-watts. Recently, dynamos have been constructed abroad which have vertical shafts and are known

as the "umbrella" type. These dynamos may be set directly over the water-wheels, the two shafts being connected together and a vertical, direct-connected unit thus produced. Fig. 33 shows the arrangement of such units. The weight of the turbine runner and of the rotating part of the dynamo, together with the vertical shaft, form a rotating mass which must be supported. Step bearings and thrust-collar devices were tried for a time, but their excessive friction and rapid wear made the horizontal units far preferable when conditions allowed their use. More recently, hydraulic thrust bearings having but little friction and inappreciable wear have been developed and are in successful operation. The ability, however, to obtain standard dynamos of this type in various sizes and speeds is so limited that designs for vertical units for this character should not be attempted without first investigating to find out if standard patterns are available for the sizes and speeds required.

Many vertical turbines driving horizontal dynamos by means of bevel gearing have been installed and some plants of this type are large and important. The author's experience, however, with heavy bevel gears, transmitting large amounts of power, has always been unsatisfactory. It is almost impossible to keep them in good condition, they absorb a large percentage of the total energy—often as high as fifteen per cent.—and necessitate constant watching and repairing. No such drives should ever be considered except for temporary plants or in locations where it is possible to use no other form of equipment. Under heads of less than 12 feet, however, vertical turbines must be used and this objectional gearing becomes necessary. Fig. 34 shows a vertical turbine driving a

FIG. 34.

horizontal shaft by means of bevel gears and the arrangement is quite clear from the figure.

*The impulse turbine* is but little used in the United States, although under certain conditions it is advantageous to install

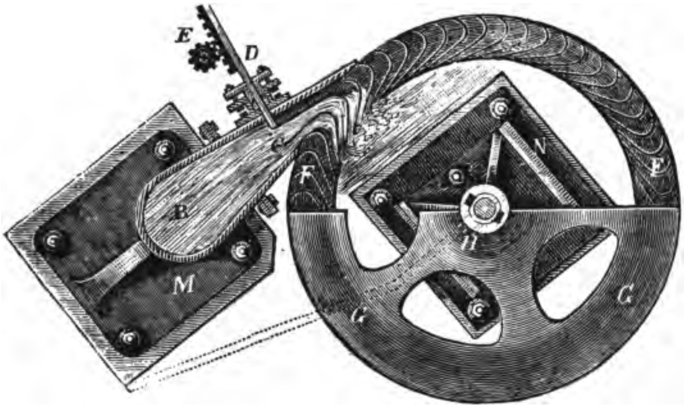



FIG. 35.

them. They differ from the previously described pressure turbines in many respects, although they are very similar in their action. The wheels themselves, or runners, are provided with a series of curved buckets which much resemble the form of buckets used in pressure turbines. Instead, however, of water being admitted to all of the buckets, and the whole structure solidly filled, the water is admitted to but few of the buckets, being carried to them and given its initial direction by one or more nozzles. Fig. 35 indicates the general arrangement of this form of water-wheel, a sectional plan being shown. The water passes from the nozzle into the wheel buckets and after passing through the latter is rejected at atmospheric pressure. Since only a few of the buckets have water passing through them—which in many instances does not fill the bucket space completely—and most of the buckets are entirely empty, it is, of course, impossible to use a draught tube and that portion of the head, from the buckets down to tail water, is lost.

These wheels, when provided with several nozzles, maintain their efficiency over a remarkable range of load change, for the reason that each nozzle acts as a separate unit on that particular portion of the wheel covered by it, and regulation for load variation is obtained by shutting off one nozzle at a time, which does not, in any wise, affect the action of the other nozzle. Also, in varying the power delivered by a single nozzle, the area or spread of the nozzle is diminished and this simply means that the number of buckets acted on by the nozzle is reduced. In Fig. 35 is shown a movable tongue at the end of the nozzle which varies its width with load changes.

The peripheral speed of the wheel is about one-half the spouting velocity of the water. As is clear from its characteristics, the dimensions of the wheel may be made nearly anything desired for a given power and head.

Where heads are 150 feet and up to 600 feet, these wheels give

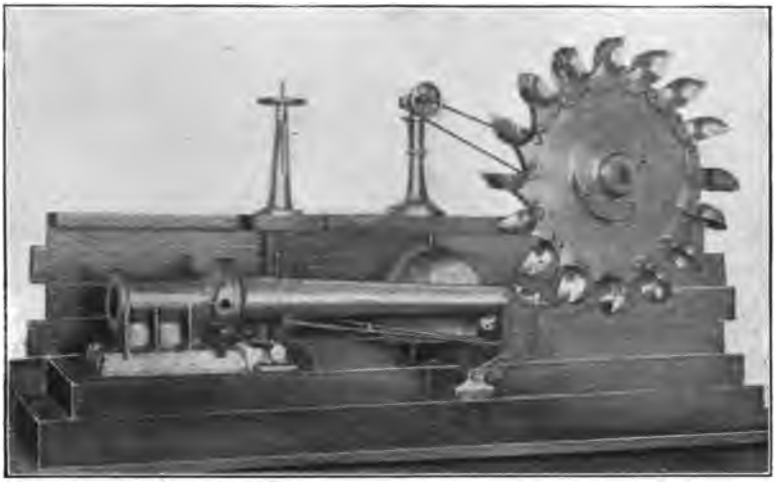


FIG. 36.

excellent results. Under lower heads the pressure turbine is preferable for the reasons that its efficiency at or near its rated load, is higher, it utilizes the total head, and is generally less expensive.

*The Pelton or jet impulse wheels* are suitable for heads above 150 feet. They have the advantages of high efficiency, simplicity, and low cost. Fig. 36 shows the general arrangement of this form of wheel. The water emerges from the nozzle at a velocity equal to $8\sqrt{\text{head}}$ and strikes against the wheel buckets. These are formed with a double curvature having a rib in the middle as shown. The water strikes against the sharp edge of the rib, divides in two equal parts, half going into one side of the bucket and half into the other. The water impinges against the bucket surfaces and at the same time sustains a change in the direction of its motion, being discharged by bounding back practically in the opposite direction to the direction of flow from the nozzle, but slightly to the side so that the reversed water does not encounter the incoming nozzle flow. The object of this design is to completely reverse the direction of flow of the water and have it leave the wheel at practically zero velocity, thus abstracting all the kinetic energy from the water.

FIG. 37.

The peripheral velocity of the wheel is practically one-half the

spouting velocity of the water, and the efficiency of this type of wheel is often as high as eighty-five per cent. In a wheel of given size, the power may be increased by simply increasing the number of nozzles, each nozzle adding a proportional amount of power. This increase generally is not to be carried further than five nozzles to any wheel, a certain distance between nozzles being necessary for the

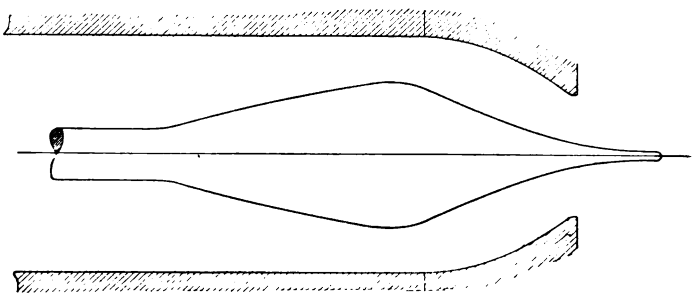


FIG. 38.

buckets to clear themselves of water received from one nozzle before receiving water from the next adjacent nozzle. Fig. 37 shows a triple nozzle to apply to a single wheel. When it is desired to obtain a high rotative speed with a given power, two or more small wheels may be placed on one shaft, each wheel giving its proportion of the power and the shaft velocity being that of a small single wheel. As in the case of the impulse turbine, the effective head is only that from the level of the head water to the wheel, that portion of the head from the wheel to the tail water being lost. This loss, however, with the high heads under which these wheels work, is a small fraction of the total available head and in such cases is practically negligible.

The wheels are usually encased in an iron shell, the discharged water falling through the opening in the bottom of the case. The power is varied either by deflecting the nozzles so that only a portion of the water strikes the buckets, or by the so-called needle control. In this latter device a sharp-pointed, conical-ended rod

works inside the nozzle as shown in Figs. 38 and 39, Fig. 38 being a sectional view and Fig. 39 showing the nozzle with a water jet passing from it. The flow of water is varied by the variation in position of this "needle." It must, however, be moved with comparative slowness, as the rapid velocity of the water in the pipes leading to the wheels will cause a destructive shock if suddenly arrested. Relief valves must always be used in connection with

FIG. 39.

needle nozzles. The deflecting jet, while it performs the function of regulation satisfactorily, is very wasteful of water under loads less than full load, as the flow of water is constant whatever the load may be

*Speed Regulation of Water-Wheels.*

There are many types of automatic speed governors for water-wheels, and improvements in these mechanisms are being made at frequent intervals. It is possible now to obtain a good regulator at a reasonable price. To describe the many varieties on the market and their methods of operation would be superfluous here.

It may be said, however, that they all use some form of fly-ball governor which, by its changes in position with speed variations, sets the gate opening or closing mechanism in motion.

These governors must not move the gates too rapidly when the water is conducted to the turbine through long pipes, for the reason that the mass of water in a pipe moves with a certain velocity with a given gate opening at the turbine, and if the gate be closed too suddenly, the kinetic energy of the moving column of water must be as suddenly dissipated. The only way that this energy may be dissipated is by the compression of the water itself and distention of the pipe. Dangerous pressures may thus be produced unless the pipe is provided with relief valves or an overflow pipe.

Conversely, if the gate be opened too quickly, the column of water cannot be instantly accelerated and it tends to break in two, that portion nearest the wheel running into the increased opening, separating from and leaving the rest of the water in the pipe, which cannot so quickly attain the necessary velocity. As a result, a space is left in the pipe which is a vacuum and the external pressure of the air tends to collapse the pipe. Such accidents have occurred and should be provided against in the design of a plant.

A peculiar effect, quite opposite from that desired, also attends rapid gate movement. If the speed of the turbine decreases and the gate be suddenly opened to cause an increase in speed, the wheel will actually decrease its speed still further, for a few seconds, due to the decrease in pressure as above described, the effect of which overbalances the effect of the increased gate opening. Also, if the speed should increase and the gate opening be suddenly decreased to bring the speed back to its normal value, the wheel speed will increase still further, due to the increase in pressure set up by the suddenly arrested water column, the effect of this increase in pressure being greater than the effect of the diminished gate opening. The speed will then gradually fall until the normal speed is attained, several seconds being sometimes required to produce the proper speed change. Consequently, the governor

should move the gates of the turbines only as fast as the column of water in the pipes can be accelerated or retarded.

The foregoing does not apply to turbines set in open penstocks nor turbines in steel casings which have one end of their shells set into the dam or bulkhead, nor do these remarks apply to installations where the conducting pipes are only a few feet long—say two or three times their diameter.

# PART II

## ELECTRICAL EQUIPMENT

## CHAPTER VI.

### GENERAL CONSIDERATIONS.

THE power in any electrical machine or transmission line is equal to the product of volts multiplied by amperes, which gives the number of watts. A kilo-watt (abbreviation K.W.) is equal to 1000 watts. A horse-power is equal to 746 watts, hence a kilo-watt = 1.34 H.P. The product of volts × amperes does not represent the actual power delivered by an alternating current system, except under certain favorable conditions, the power being usually less than the volts × amperes by a percentage which depends on the constants of the system. The *real* power is equal to volts × amperes × $\phi$, in which $\phi$ is a factor called the *power factor*. Only when the power factor is equal to 1—as it is in all direct-current systems and in all alternating-current systems in which the load is non-inductive, such as incandescent lamps, electrolytic tanks, synchronous motors, or rotary converters—is the actual power equal to volts × amperes.

The power factor of arc-lamp circuits is about 0.82, of induction motors from 0.85 to 0.9, according to construction and size. The use of the power factor in calculations will be shown in later discussions.

There are, in general, two systems, between which the designer of a power station may choose—namely, the alternating and the continuous or direct current.

To consider the origin, interaction, and conditions of electric

and magnetic phenomena is beyond the scope and intention of this work. The reader who desires to pursue this portion of the subject further, is referred to any of the many excellent treatises on electricity and magnetism that abound in all languages and may be obtained in nearly any locality. It therefore suffices to say here that continuous current flows always in one direction through an electric circuit or machine, and is the same kind of current as is given out by an electric battery, while alternating current flows first in one direction, then in the opposite direction, then reverses again, and continues to change its direction of flow as long as the electricity is produced. These reversals are very rapid and take place at a rate of from 50 to 250 times per second, or from 3,000 to 15,000 per minute. If current were supplied to lamps by a battery and a switch were connected in the circuit so that when turned in one position the positive pole of the battery is connected to one of the wires and the negative pole to the other wire leading to the lamps, while if the switch be turned to another position it will connect the positive pole of the battery to the second wire and the negative pole to the first, and this switch were rapidly moved back and forth, the current to the lamps would be similar to the alternating current produced by alternating dynamos. Each of these systems has its particular place in the art and in some cases either is suitable for a given kind of work.

The advantages of the direct current are as follows: Direct-current dynamos and motors may be obtained in a greater variety of speeds and sizes from standard patterns; the motors will give a stronger starting torque and continue to run under heavier overloads than will alternating-current motors; it is the only current which will operate storage batteries and in connection with them; it, only, can be used in electroplating and electrolytic work of a like character; its phenomena are much simpler, easily calculated and understood than are the laws which apply to alternating currents. It has the disadvantage, however, of requiring a commutator on each dynamo or motor, with brushes bearing against it which limits the voltage of the machines and also, when

the voltage of a direct-current system is once fixed, this also is the voltage of all the distribution lines and branches with their ramifications and it cannot be altered except by the use of electrical machinery.

The advantages of the alternating current over the direct current are: The dynamos and motors are simpler in their construction and cost less than direct-current machines of similar capacity; the voltage may be transformed from any value to any other that may be desired by the use of simple and low-priced static transformers which have no moving parts and consist merely of two coils of wire wound on an iron core. Furthermore, in the case of three-phase alternating current, the amount of wire required to transmit a given power over a given distance is twenty-five per cent. less than the amount required for a similar direct-current transmission. As will be shown later, the use of high voltages is necessary when electrical energy is to be transmitted over long distances, and, in even as short a distance as one mile, the proper voltage is greater than that which is produced by any standard direct-current machine for power service that is made in the United States. Electric railways are best operated by 550 volts direct current, and the standard available railway equipments are all for this voltage. Therefore, in general, the system chosen should be direct current when the distance of transmission is short and the power is to be used on electric railways, for electrolytic work, or for supplying power to mills and factories where the speed of the machinery has to be varied through a wide range and the initial starting effort of the motors must be high. In cases where the conditions require the use of alternating current, but some direct-current is needed, an alternating current system should be installed and the small proportion of direct current needed may be obtained by using a rotary converter or a motor generator set, which latter is made up of an alternating current motor driving a direct-current dynamo.

In every alternating-current power station there are also placed small direct-current dynamos, called exciters, the current from which is used to magnetize the field magnets of the alternating-

current generators. In many instances the capacity of these exciters is made great enough to supply not only the needed field exciting current but to furnish some additional current for other purposes as well. In a power station, recently designed by the author, the exciters installed are large enough to furnish current for lighting the power station and certain adjacent buildings, in addition to supplying the necessary field excitation to the alternating-current dynamos. The reason for the adoption of this method of lighting was that the voltage of the power dynamos was subject to considerable variation which would have manifested itself by variation in the illumination if the lamps had been supplied from these machines.

In deciding on the size and type of dynamo to be used it must be remembered that the lower the speed at which it runs the greater will be its cost for a given capacity. For this reason it is frequently cheaper to make use of a high-priced turbine which runs at a high speed than to purchase a lower-priced low-speed turbine when the machines are to be directly connected together. Thus, a single turbine of 500 H.P. operating under a 50 foot head will cost about $1,800 and will run at about 275 r.p.m. Two 250 H.P. turbines on a single shaft will cost $2,100 and run at 450 r.p.m. The cost of the 375 K.W. alternating-current dynamo, running at the speed of the single wheel, will cost $4,800, making the cost of the low-speed unit complete $6,600, while a dynamo of similar capacity at the higher speed will cost $3,800, making the cost of the high-speed unit complete $5,900, so that by using the higher-price turbine a lower cost generating unit is obtained.

The size of the dynamo to be used in a power station is generally obtained as follows: the gross horse-power to be developed is computed by the methods given in a previous chapter. Eighty per cent. of this is available at the turbine shaft. The dynamo efficiency, including the power required to operate the exciter, is about 92 per cent. The total dynamo power, therefore, is 92 per cent. of 80 per cent. or 73.6 per cent. of the gross available power. The total dynamo power thus found should be divided among several

machines, and, where possible, the number of the machines should not be less than four nor should the number exceed ten. When as many as four machines are used, if one should break down the other three, working at 20 to 25 per cent. overload, would deliver nearly the full power of the station.

The water-wheels should each have a capacity 15 to 20 per cent. greater than the power required to drive its dynamo. It sometimes is better to drive dynamos by belts from pulleys on the water-wheel shaft, or in large sizes, to use rope drives, than to connect directly the two shafts. This is frequently true in the case of low heads where turbine speeds are so low that the high cost of the generators would make the investment for direct-connected units excessive. When belted units are installed, however, the distance required between the centres of the two shafts, in order to give sufficient length to the belt, increases the size of the power-house and likewise its cost. Before deciding, therefore, on whether or not it is best to use belted or direct-connected units, computations should be made showing the comparative total cost of the units, plus power-house for each case. In making this computation the item of belting should not be omitted as high-grade, double leather belts cost about 16 cts. per foot for each inch in width. Thus a 30-inch belt will cost $30 \times 16 = \$4.80$ per foot length, and with 25 feet between centres and usual size pulleys about 60 feet of belting are required, costing $288.00. The extra cost of the pulleys should also be included.

## CHAPTER VII.

### ALTERNATING-CURRENT DYNAMOS.

THERE are many kinds of alternating-current dynamos, but at the present day the only sorts which are in general use are the revolving field and the inductor types. The inductor, while an excellent form of machine, is being almost entirely supplanted by the revolving-field machines, owing to the lower cost of manufacture of the latter.

Inductor dynamos are constructed as indicated in Figs. 40 and 41. Fig. 40 shows the complete dynamo, while Fig. 41 shows the inductor with its central magnetizing coil. The armature winding is placed in slots or grooves cut on the inner surface of the stationary ring of laminated iron which surrounds the inductor and is held in position by the external iron frame of the dynamo. The inductor itself consists of a wheel, having mounted on its rim a number of masses of laminated iron arranged in pairs, side by side and equally spaced around the circumference of the inductor wheel as indicated in Fig. 41. Encircling the rotor, but not in contact with it, is the circular channel carrying the magnetizing coil, which corresponds to the field winding in other forms of dynamos. This single coil, which is stationary and does not rotate, magnetizes all of the rotating masses of iron on the inductor wheel. As is obvious from the figure, all of the masses of iron on one side of the coil are magnetized as north poles, while those on the other side of the coil are magnetized as south poles, the magnetic circuit being completed through the laminated iron ring encircling the inductor, which is separated from the magnetized portions of the inductor by only a small air gap. There is no moving wire whatever in this form of dynamo and consequent-

ly it is not necessary to use collector rings and brushes, all connections to the field and armature windings being made in the ordinary manner as they are both stationary. This description and the figures apply of course to but one particular type, but there are

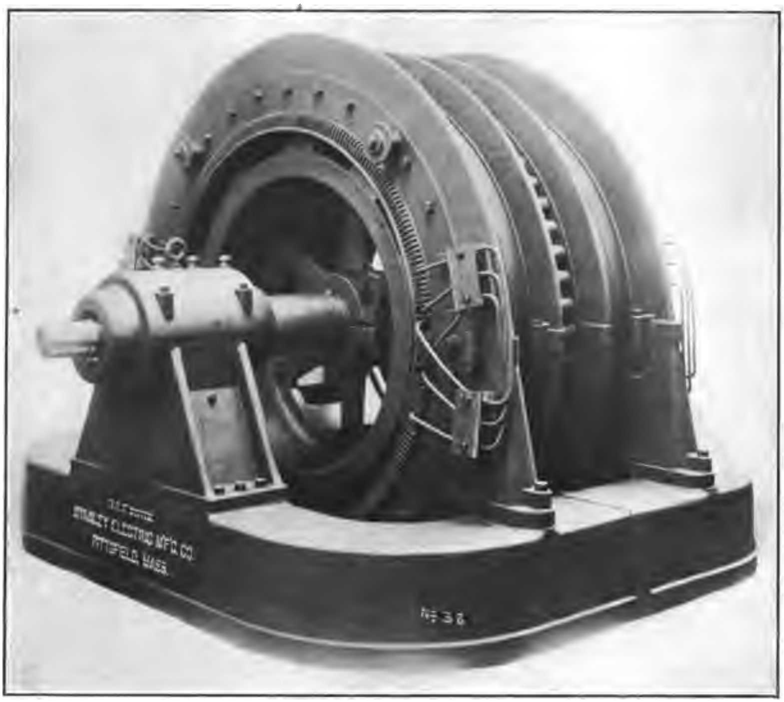



FIG. 40.

several forms of inductor machines which have no moving wire, and which work on the principles outlined above.

Dynamos of this kind are durable, usually of high efficiency, and they are in every respect satisfactorily operating machines. Their one disadvantage is their high cost of manufacture.

The revolving-field alternator is similar to the inductor alternator in that its armature winding is stationary, the coils being

embedded in slots made in the outside ring of laminated iron. The rotating part consists of a wheel having fastened to its periphery a number of short field-poles, equally spaced around the circumference and projecting radially outward towards the encircling stationary iron ring, carrying the armature winding. Each of these field poles is surrounded by a field winding and the outer ends of the poles approach very near to the inner surface of the stationary iron ring, a small air gap separating them. Figs.

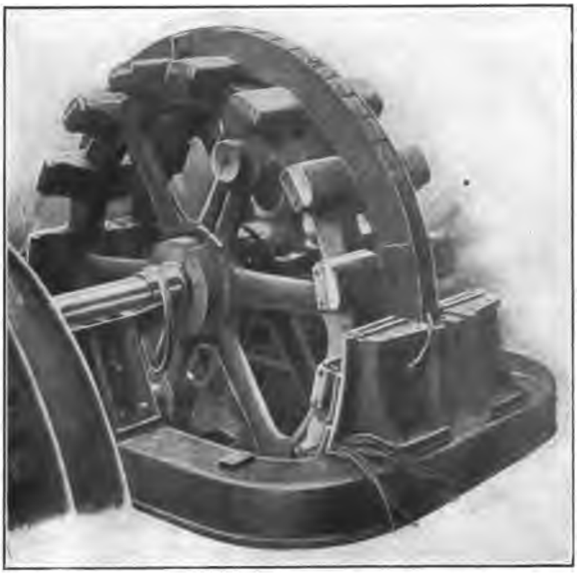


FIG. 41.

42 and 43 show the stationary ring carrying the armature windings and the rotating field member (or rotor) respectively, of a standard machine of this type. The complete machine is shown in Fig. 44. The connections to the armature are made without collectors or brushes. The field-magnet windings all rotate and it therefore is necessary to transmit current to them through collector rings, having brushes bearing on them. The

field current, however, is always very small and the voltage low as compared with the output from the armature, and, therefore, the size of the brushes and collector rings is small, and there is no

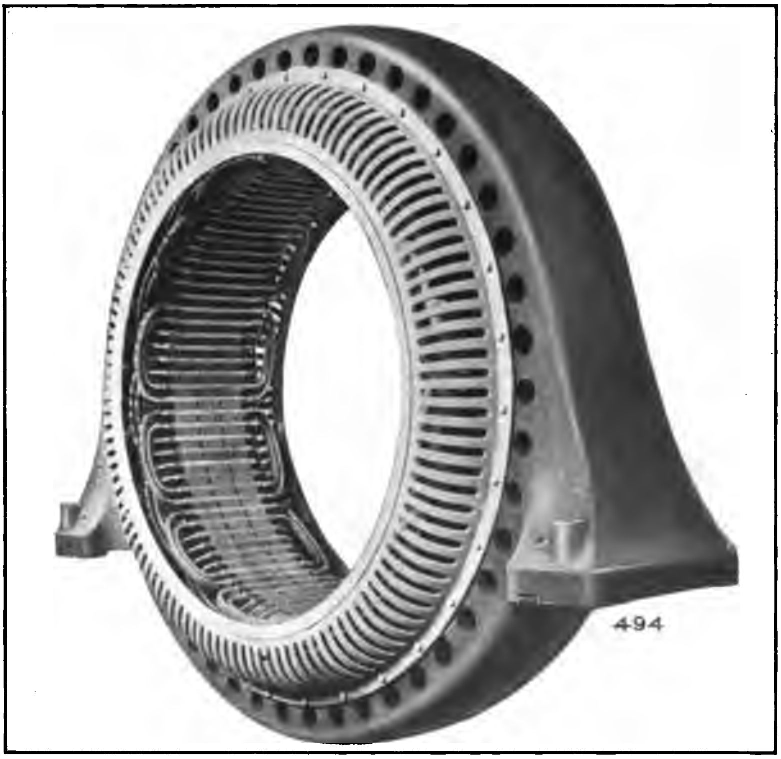



FIG. 42.

difficulty whatever in their operation. This type of machine may be constructed at a low cost and they are so thoroughly satisfactory that they are almost exclusively used in the United States at the present time.

Both the inductor and rotating-field machines have one advantage in common, viz., the stationary armature winding and direct connection from it to the outgoing transmission line without

the use of collector rings and brushes. This admits of insulating the armature winding to the same degree that a transformer winding may be insulated, and, in consequence, dynamos may be wound for extraordinarily high potentials, it being easy to obtain machines in many standard sizes which deliver 6,600 volts and a few have been made which give 13,000 volts. For comparatively short transmissions—say up to fifteen miles—these potentials are high enough and the use of step-up transformers and the expense of purchasing them are avoided.

FIG. 43.

Practically all generators used for power transmission are for three-phase currents, the three-phase system now being standard for this work, as the costs of the generators and of the line copper are less than for any other system. There are two frequencies which also have become standard, viz., 60 cycles and 25 cycles per second. The higher frequency is suitable for, supplying current to motors and to lamps, either incandescent or arc. It, however, has the disadvantage of giving a higher line drop and poorer regulation on long transmission lines than does the lower frequency, and, furthermore, it is difficult to operate rotary converters at 60 cycles. Generally, the costs of transformers, dynamos, and motors are somewhat less for the frequency of 60 cycles than for 25. The frequency of any dynamo is equal to the number of poles × revolutions per minute ÷ 120, and conversely the number of poles in a machine are equal to alternations per minute ÷ revolutions per minute or equal to cycles per second × 120 ÷ revolutions per minute.

The lower frequency has the disadvantage of being unsuitable

for lighting, and dynamos, motors and transformers cost slightly more than those for 60 cycles. The inductive drop on a long transmission line, however, is less and rotary converters operate with ease at this frequency. Therefore, in choosing the frequency,

FIG. 44.

the character of the load is the determining factor. If the line is short and there is considerable lighting load and but a small amount of direct current is required, 60 cycles is the proper frequency. The direct current may be obtained by using small rotary converters which can be made to work fairly well at 60 cycles, or by using direct-current generators driven by alternating-current motors. If the line is long—60 miles or more—and a large amount of direct current is required at the distributing end of the line and the lighting load is comparatively small, 25 cycles

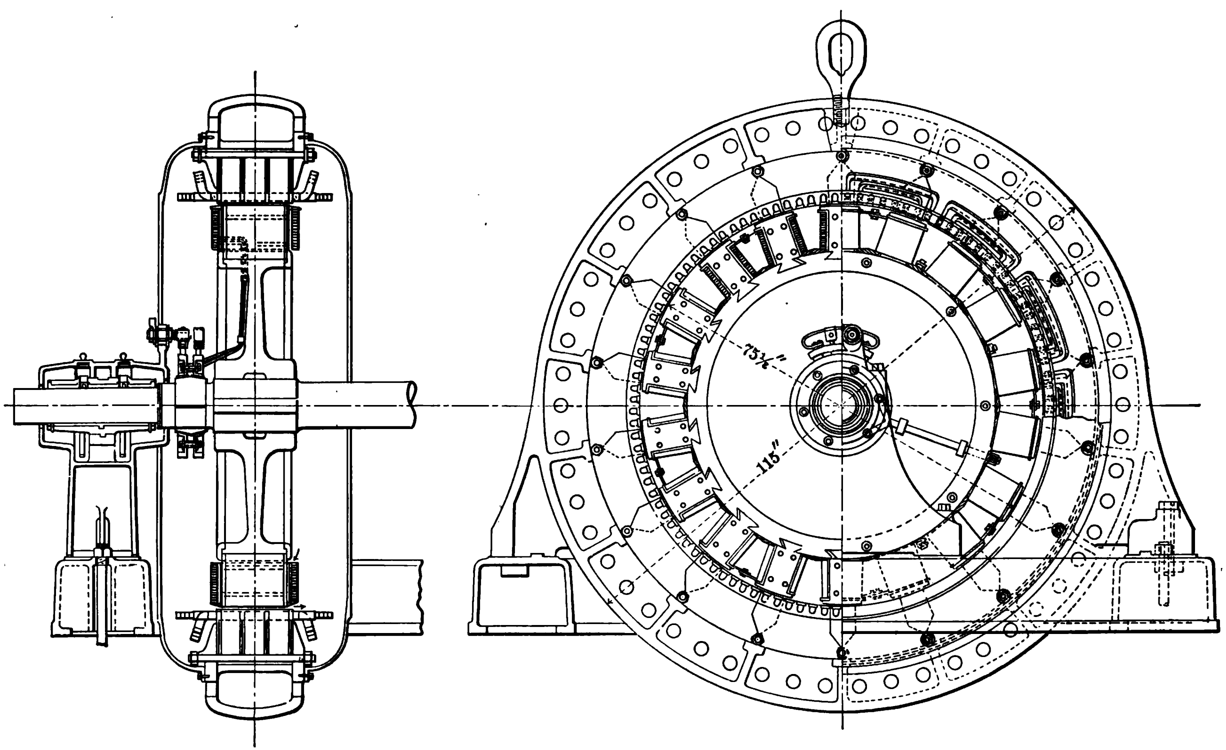



FIG. 44a.

is the better frequency. In any case, where the larger part of the load is to be in the form of direct current, as for instance an electric railway system, the low frequency should always be adopted, in order that rotary converters may be used and made to work satisfactorily in parallel.

These factors may vary in such a manner as to render a decision somewhat difficult, and the only thing to do in such a case is to investigate carefully various operating plants supplying service somewhat similar to that contemplated in the prospective plant, and profit by the experience of others.

Dynamos are made in various efficiencies, the efficiency depending somewhat on the cost. High-efficiency machines require more iron and copper to construct than do those of low efficiency. The word efficiency is used here in its technical sense and is equal to the power which is delivered by a dynamo divided by the power which must be applied to the dynamo shaft in order to obtain the delivered power. In a 1,000 K.W. machine the efficiency may be from 92 to 96 per cent. This means that from 4 to 8 per cent. of the total power furnished is lost in the dynamo, which loss goes into the form of heat, the temperature of the copper and the iron being raised above that of the surrounding atmosphere and a constant radiation thus produced, which dissipates a certain proportion of the total energy. Some of this lost power is also used up in driving the small exciter dynamo which furnishes current to the field magnets. The energy thus lost in a 1,000 K.W. dynamo will be from 40 to 80 K.W. or from 54 to 108 H.P. Whether it is better to pay a higher price for the dynamo of higher efficiency or not, depends entirely on the conditions that obtain in any particular plant. If the water power is abundant and greater than will ever be used in the locality where the development is made, the low-efficiency machine should be used. If, however, the water power is limited and the value of power high, the high-efficiency dynamo should be installed. Taking the case of the 1,000 K.W. dynamo above, at the two extremes given, the salable power from the high-efficiency dynamo is 54 H.P. in excess of that from the

low-efficiency machine, the water power being the same in each case. If this power is salable at $15.00 per annum per H.P., the income that may be derived from the high-efficiency dynamo is $810.00 per annum more than the income obtainable if the low-efficiency machine be used. Assuming that all increase in expenditure above that absolutely necessary to get the plant in commission must return 15 per cent. on the added investment, $5,400.00 more could be paid for the high-efficiency machine than for the one having the low efficiency. The actual excess cost would not exceed $1,000.00, so it is evident that the high-efficiency machine is the better paying one. This same reasoning applies also to turbines. These considerations are of great importance in every case where power is limited and should receive careful consideration.

Another vital question is that of regulation. This is defined as the percentage change in the voltage of a dynamo between the limits of full-load current and no load, the field excitation and speed remaining unchanged. All variations in voltage at the dynamo will be transmitted over the line to the points of distribution and, in the case of rotary converters, cause a corresponding change in the direct-current voltage and thereby produce fluctuations in the direct-current service. Also, where lights are fed from the line or from rotary converters the fluctuation in brilliancy with even small changes in the voltage are marked and the service is unsatisfactory.

On the other hand, if the load be entirely of motors, a greater voltage change is allowable and good regulation not so necessary.

Dynamos having high efficiency always have good regulation also, that is, the change in voltage with change in load is small.

The best machines have a regulation of 6 per cent. on non-inductive load or 8 per cent. on an inductive load of 85 per cent. power factor, while some standard machines have a regulation of 14 per cent. on non-inductive and 18 or 20 per cent. on inductive loads.

The regulation of generators for long transmissions should be as good as possible for the reason that the drop in potential from

the generator to the receiving motors or other translating devices is the sum of the drops in the generator and in the line, and both of these increase with increase in current. Generally, the load on a transmission plant, though subject to variation, does not fluctuate sharply, the changes in load taking place gradually, and the line and generator drops may be compensated for by variation in the generator-field excitation. Therefore, the character of the load influences the degree of regulation necessary, sharply fluctuating loads requiring a better regulation of line and generators than gradually changing loads which are subject to rheostatic control of the exciter.

At present, automatic voltage regulators can be purchased in the open market at reasonable prices. These automatically adjust the field excitation to give a constant voltage at the dynamo terminals no matter what the inherent regulation of the machine itself may be. They may be adjusted to cause an increase in voltage with increase in current, thereby compensating for the increased line drop, the effect being practically similar to that of an over-compounded direct-current dynamo. They are independent mechanisms and may be applied to any generator and, in the case of dynamos of 200 K.W. and above, it is usually cheaper to install a dynamo having a low regulation factor, and purchase the voltage regulator to work with it, than to pay the higher price for the dynamo having a better regulation. Furthermore, the operation of the automatically controlled dynamo is superior to that of one having the best possible inherent regulation and not so controlled.

The speed regulation of the units may be allowed to fluctuate somewhat, if the voltage is automatically maintained constant, provided current is not furnished to any synchronous motors or rotary converters. Since all synchronous machinery operates at exactly the same electrical speed—*i.e.*, the time of rotation from one pole to the next adjacent pole—as that of the generator, and this relation is as rigidly fixed as if the machines were geared together, any change in generator speed must be accompanied by an

exactly corresponding change in the speed of the synchronous machine. Therefore, a sudden change in the dynamo speed may result in the synchronous machine running out of step with the generator alternations, due to the fact that the fly-wheel effect of the rotating parts of the synchronous machines will prevent them from suddenly speeding up or slowing down to conform with the sudden changes in generator speed. As a result, the synchronous machines will slow down and stop and, during the period of stopping, heavy surging of current will take place on the line which, for the time, will destroy the regulation and may set up injurious voltages due to inductive or resonance effects. Therefore, the provision for speed regulation must be very much more elaborate when synchronous machines are to be operated than when the energy is supplied only to lights and induction motors. Of course, gradual changes in speed do no harm if they take place slowly enough to allow the speed of the synchronous machines to follow such variations. Frequently, heavy fly-wheels are placed on the turbine shafts and these, when properly proportioned for the speed and probable maximum load changes, are effectual in prevention of sudden speed fluctuation.

The required capacity of the dynamos depends not only on the power to be delivered but the character of the load. If the current is all used by incandescent lamps or synchronous machines, the power factor will be approximately equal to 1 and the dynamo capacity, in kilo-watts, will be equal to the actual power requirement of the lamps and machines supplied, plus the loss in the line. If, however, the energy is supplied to induction motors or arc lamps, the power factor will then be considerably less than 1, its value being usually somewhere between 0.8 and 0.9.

The power factor may be defined, in plain words, as the ratio of the actual energy supplied, to the required generator capacity. That is, the load in kilo-watts divided by the power factor is equal to the required K.W. capacity of the generator. Therefore, if the K.W. requirement of the load is equal to 1,000 K.W. and the power factor is 0.8, the capacity of the generator must be

1,000 ÷ 0.8, equal to 1,250 apparent K.W. If the generator voltage is 1,000 volts, the current—assuming a single-phase transmission—will be 1,250 amperes. The actual energy supplied, however, is only 1,000 K.W., and although the generator may apparently deliver 1,250 K.W., the actual load on the water-wheel is only 1,000 K. W., plus the losses in the generator. Under these conditions it is clear that the energy supplied is equal to the product of volts × amperes × power factor. The product of volts × amperes is called the apparent watts, and owing to the fact that the power factor may vary, so that the actual kilo-watts supplied by a given current under a given voltage may correspondingly vary, it has become customary to express the capacity of alternating current generators in kilo-volt-amperes (abbreviated K.V.A.) instead of kilo-watts. It is obvious, therefore, that where the power factor is 0.8, the size of the generator must be 25 per cent. greater than the computed load requirements would indicate, or if the power factor were 0.9 the generator would have to be of 11 per cent. greater capacity than the load demand shows. This increase in generator size does not require a corresponding increase in the power of the turbine, because with a power factor, for instance, of 0.8 the generator may deliver apparently 1,250 K.W. while the actual energy output will be only 0.8 times this or 1,000 K.W. In other words, a power factor requires an increase of current to deliver a given amount of energy and the dynamo must be large enough to furnish this increased current without overheating.

When current is passed through any conductor, heat is liberated by an amount proportional to the resistance in ohms of the conductor and to the square of the current in amperes, or $H = I^2 R$. Also with repeated reversals of magnetization, such as rapidly occur in electric generators, a certain amount of energy is absorbed proportional to the number of reversals, the mass of the iron affected, and the magnetic density. This absorbed energy also manifests itself in the form of heat. Both of these conditions for the generation of heat are present in every electric generator and as a result the temperature of a dynamo will rise above that of the surround-

ing air until it attains a value such that it can radiate the heat as rapidly as it is produced. Since dynamos are made with certain materials in them, such as cotton and fibre, which are used for insulating purposes and which deteriorate rapidly under the influence of high temperatures, they should be designed and proportioned so that the rise in temperature shall not be very great. The greater the amounts of iron and copper in a dynamo or motor per K.W. of output, the smaller will be the temperature rise. Other things being equal, the smallness of the temperature rise is a measure of the excellence and value of the dynamo. The same factors in design which produce high efficiency and good regulation also give a small temperature rise. In fact, since the efficiency measures the energy lost in the generator and this energy loss is continuously dissipated in the form of heat, the efficiency practically measures the temperature rise, modified, of course, by certain characteristics of design to ventilate the heated portions. It has been found that about 165° F. or 74° C. is about the maximum temperature that insulating materials will stand continuously without deterioration. In temperate climates it is assumed that the temperature of the surrounding air will rise to 90° F. or 34° C. and on this basis the increase in temperature above that of the surrounding air has been fixed at 40° C. To obtain a smaller rise would increase the cost of the dynamo or motor by an amount in excess of the value which would accrue, while if the machine were made at a less cost for a greater temperature rise the insulation would deteriorate too rapidly and the efficiency be too much reduced to make such machines desirable at any price. The standard fixed, of between 35 and 40° C., is a commercial compromise between ideal scientific, and practical business conditions.

Dynamos which are to be installed in places where the temperature of the surrounding air will be greater than 90° F. or 34° C., such as in tropical latitudes or adjacent to boiler plants, must have a corresponding allowance made in the permissible temperature rise. Thus, if the dynamo-room is subject to a temperature of 44° C. for a prolonged period of time, the allowable

temperature rise of the dynamos should be limited to 30° C. If this high temperature is attained only occasionally, the temperature rise and total temperature attained may be 5 or 10° C. in excess of these figures.

From these considerations it is obvious that dynamo-rooms should be as well ventilated and maintained as cool as possible.

*Exciting Dynamos.* The small direct-current dynamos which

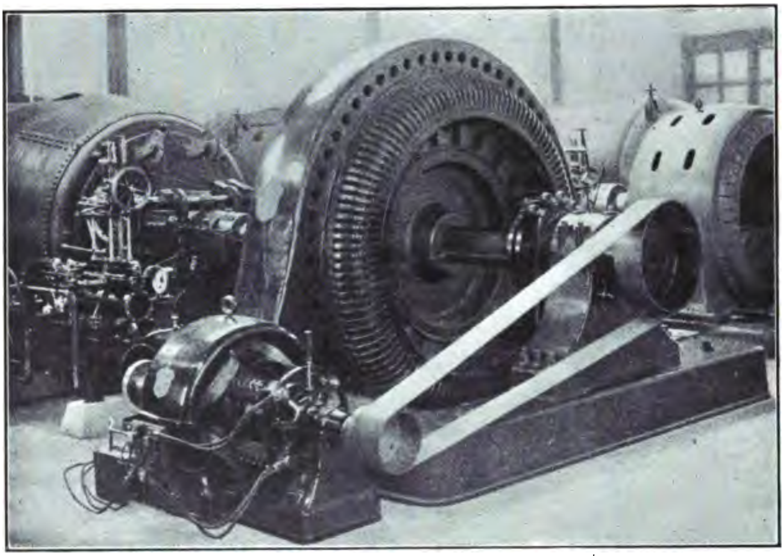


FIG. 45.

supply current to energize or "excite" the field magnets of the generators are usually standard 125 or 250 volt machines. In small power stations it is usual to drive the exciter by means of a belt which receives its power from a pulley on the shaft of the main dynamo. Fig. 45 shows this arrangement. In some instances the exciter is mounted on the same frame with the main dynamo and its armature is placed on an extension of the main dynamo shaft, producing in effect, an exciter direct-connected to the main dynamo. This is shown in Fig. 46. It has the advantage of eliminating

the driving belt and pulley and requiring less space for each unit. It, however, has the disadvantage that the small machine runs at the same speed as the large one to which it is connected and this, of course, is necessarily an extremely low speed for the small machine. As a result the cost of the exciter becomes abnormally great and its efficiency also is reduced.

With either the belted or direct-connected exciter, each alter-

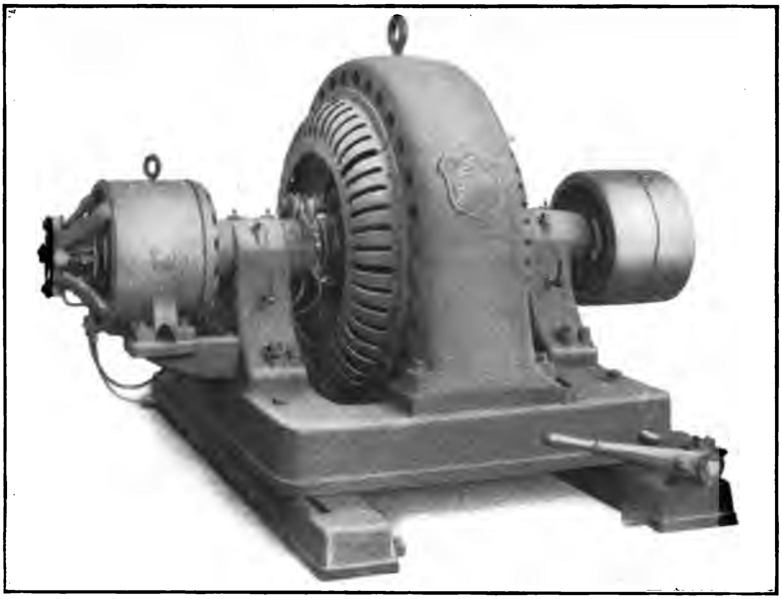


FIG. 46.

nator is provided with its individual exciter. In the larger power stations it is customary to install only two exciters regardless of the number of alternating-current generators. Each of these machines is driven by its own turbine to which it usually is direct-connected except when the head on the water-wheels is too low to obtain a turbine speed corresponding to the exciter speed. The sizes of the exciters and their driving turbines are such that either exciter will furnish sufficient current to energize the field magnets

of all the generators in the station. Only one exciter is operated, the other being held in reserve as a spare in case of accident.

Fig. 47 shows the usual connections between the exciters and generator fields. $E1$ and $E2$ are exciter armatures connected to the bus-bars $L1$, $L2$, by switches $S1$, $S2$ respectively. $r1$, $r2$ are rheostats in the exciter fields to adjust their voltages. $F1$ and $F2$ are the generator fields connected to the bus-bars by the field switches $FS1$ and $FS2$. Rheostats $R1$ and $R2$ are inserted in the generator-field circuits so that the excitation of these fields may be adjusted independently of each other. When each generator is pro-

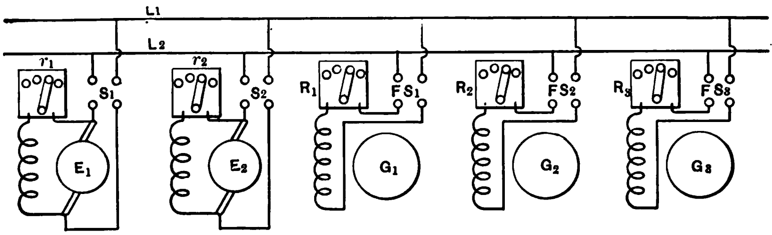



FIG. 47.

vided with its own separate exciter, the excitation of the generator field is varied by adjusting the exciter-field rheostat so that the exciter armature gives just the required voltage to produce the desired field excitation, the resistance of the main dynamo rheostat being practically all cut out, thus minimizing the energy loss from the exciter.

As explained in discussing temperature rise of the main dynamos, the capacity of exciters should be such that they will never attain a temperature above 74° C.

The exciting current required by any alternating-current generator should not vary greatly with change in load on the generator. It is usual to specify that the required field excitation at full load with 80 per cent. power factor shall not be more than 20 per cent. in excess of that required to produce the same voltage at zero load, the speed of the generator being the same under both conditions.

The proper voltage of generators is fixed by the transmission conditions which are discussed in chapter IX.

## CHAPTER VIII.

### TRANSFORMERS.

As will be presently set forth under the subject "Transmission Lines," high voltages are essential on long-distance lines for commercial reasons. Generally, where the pressures exceed 6,600 volts it is not expedient to produce it directly in the generator windings, and transformers are used which receive the generator current at some low voltage and transform it into practically the same amount of electrical energy of less current at much greater voltage. When so used they are termed "step-up" transformers. The generator voltage when step-up transformers are used may be anything desired, as the cost of transformers is dependent only on their K.W. capacity and the voltage of the high-tension side. It is usual, therefore, to install generators that give 1,000 to 2,000 volts, where step-up transformers are used to produce the necessary line pressure, and in many cases 440 volt generators are adopted. It is better to use low-voltage dynamos in connection with step-up transformers, as they are less dangerous, there is less liability to break-down due to failure of insulation, and the switchboard equipment is reduced in cost, except in cases where the kilo-watt capacity of the plant is so great that the currents at the lower voltage become extremely large, in which event the excessive size of the switches and instruments and the panels on which they are mounted makes the cost of the switchboard equipment higher than it would be for smaller devices constructed to work under greater pressures.

The high tensions used for transmission are not suitable nor applicable to motors, lamps, or other translating devices, and it therefore is necessary to reduce the voltage at the receiving end of the

transmission line, which reduction is effected by means of transformers similar to the step-up transformers. Where they are used for voltage reduction they are called "step-down" transformers.

The transformers at the power station are usually located in an extension of the dynamo-room. When they are small, say not above 100 K.W. in size, they are placed in rows in the extension provided for them, with ample space around each one so that it may be inspected from every side. In the case of large transformers, the best practice requires that a separate brick or concrete chamber be constructed for each transformer, with a door of iron on the front of each chamber, made to slide or to roll out of place so that the clear opening obtained when the door is moved is equal practically to the area of one side of the chamber. In practice the construction adopted is to make a long room of comparatively small height and depth and separated into a number of compartments by means of concrete or masonry division walls, each compartment being a fire-proof containing-chamber into which a single transformer may be placed. This arrangement is particularly necessary in the case of oil-cooled transformers, as there is danger of conflagration at times when sudden arcs occur due to break-down of insulation which sometimes takes place. These fire-proof chambers add but little to the cost of a power-house and should always be installed when practicable. They give the additional advantage of preventing the attendants from coming in contact with the high-tension terminals or receiving dangerous shocks from static discharges which sometimes occur.

In order to render the transformers accessible for inspection and repair, they are usually mounted on an iron frame having small rollers under them, so that any one may be rolled out of its compartment with ease and quickness. Many stations have the floor level of the transformer chambers about twenty inches above the floor level of the station itself, with a track running along in front of the row of compartments. A small car, having its platform on a level with the floor of the compartments, runs on this track, and with this arrangement any transformer may be rolled out onto the

car and conveyed to the repair-room or any other place provided for inspection and repair of these devices. This is a somewhat elaborate construction and suitable only for the larger power-houses of 6,000 K.W. or more.

Some engineers prefer to construct a separate building for the transformers, a short distance from the generating station. This is by no means a necessary plan, however, and its general adoption is not to be advised, though certain peculiar conditions may sometimes make it desirable.

Transformers being simply special forms of electric generators in which the lines of forces are cut by varying the magnetic flux instead of mechanical rotation, they are subject to the same laws and commercial considerations as are the dynamos in the power plant. They are subject to temperature rise, and in order to cut down their cost for a given output it is customary to employ some means of artificially cooling them, when they reach a size of 100 K.W. or more.

The methods of cooling in general use are: (1) by an air blast from a blower; (2) by filling the transformer case with oil which is circulated through pipes that are surrounded by water which abstracts the heat from the oil, thus maintaining the temperature in the case at a safely moderate value; and (3) by arranging a coil of pipe inside the transformer case, the case being filled with oil, and circulating water through the pipe coil and thereby abstracting the heat from the oil. Fig. 48 shows the last-named type with the casing removed. The coil of pipe for the circulation of cooling water is clearly shown.

The air-blast transformers are generally used in the sub-stations at the end of the line, while the oil-filled transformers, cooled by a coil of water-filled pipe inside the casing, are used at the power station for raising the transmission voltage, it being usually the case that plenty of water for cooling purposes is available at the power station, while little or none is obtainable at the sub-station unless purchased from a water-supply company at prohibitive rates.

At the power station, the cost of maintaining the water cir-

culation is *nil*, as the head on the water-wheels will also force water through the cooling coils. When the transformers are placed above the level of the head water, a siphon arrangement can be

FIG. 48.

used if the maximum lift of the water is not over ten feet above the level of the head water and the head itself is twenty feet or more.

The oil in the transformer case acts also as an insulator preventing break-downs and re-insulating any puncture that may occur due to abnormal voltages from surges on the line. It also prolongs the life of the insulating materials used in the construction of the coils, so that its value is twofold.

As in the case of generators, transformers have a certain efficiency and regulation and these are dependent on the amounts of copper and iron used in their construction and, therefore, on the cost.

Good transformers have efficiencies ranging from 96 to 98 per cent., depending on the size and design. The regulation is from 3 to 7 per cent. The desirable efficiency is a commercial question and determined in the same manner that the efficiency of the generators is fixed. The regulation is also settled by the same considerations which govern the selection of the generator regulation.

This latter, however, is not a serious matter if automatic voltage regulators be used.

The capacity of the transformers is determined by the method of computation given in chapter IX. In three-phase systems any number of generators may be used, all working in parallel and all delivering their power to one set of bus-bars. From these bus-bars, the power passes to the transformers which are also connected in parallel to a set of high-tension bus-bars which latter supply current to the transmission line. With this arrangement, it is evident that the number of transformers necessary bears no relation to the number of generators. For 3-phase systems the number of transformers must be divisible by three, however, as there are three high-tension bus-bars to deliver current to three outgoing transmission wires.

Many engineers prefer to install three transformers for each generator, with switching arrangements for connecting any three transformers to any one of the generators direct, and putting the high-voltage windings of the transformers, only, in parallel. There is no good reason for this practice and there are several reasons against it. A given capacity costs less in a few large-size transformers than it does in a larger number of smaller sizes and, also, each transformer is a possible source of trouble and it is not good practice to multiply any such possibilities. Large transformers have a slightly higher efficiency for the same character or construction than smaller ones.

Transformers should be well protected against lightning, as they receive any discharge that reaches the station. They should always have their cases well grounded, so that there can never be any dangerous potential between the case and the earth to imperil the lives of the attendants. Recent practice seems to favor connecting the secondary windings to earth, so that in case of a breakdown of the insulation between the high-tension and low-tension windings, no high voltage can be maintained between the low-tension winding and the earth.

There are three general methods of connecting transformers for three-phase circuits; namely, Y connection, Δ or mesh connection, and resultant mesh connection. The first two methods require three transformers or a number which are connected in three parallel groups, while the third method requires only two transformers or a number which are connected to form two parallel groups.

The Y connection is shown in Fig. 49. $P_1$ $P_2$ $P_3$ represent the primary windings of transformers 1, 2 and 3, respectively, $T_1$ $T_2$ $T_3$; the three wires of the incoming transmission line, $S_1$ $S_2$ $S_3$ the secondary windings of the three transformers, and $D_1$ $D_2$ $D_3$ the wires of the distribution circuit. As is clear from the figure, a high-tension wire is connected to one side of each primary winding of each transformer, the other three terminals of the windings being joined together. Similarly, the three secondary windings have each a terminal connected to one of the distribution wires, while the other three terminals are joined together.

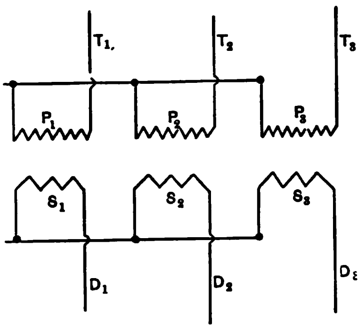


FIG. 49.

The Δ or mesh connection is as shown in Fig. 50. One terminal of the primary $P_1$ is joined to a terminal of $P_2$, the other side of $P_2$ being connected to a terminal of $P_3$, while the remaining terminals of $P_1$ and $P_3$ are joined together. The three transmission

wires $T_1$ $T_2$ and $T_3$ connect to the three junctions between the coils as indicated. The connections of the secondary coils to the three

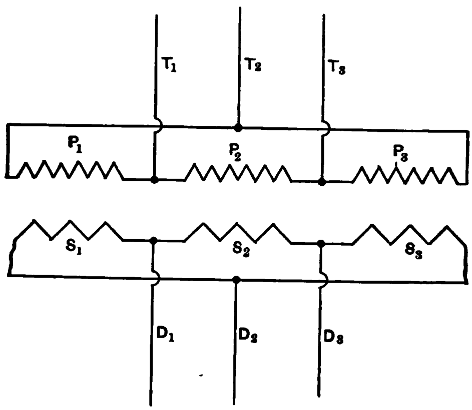



FIG. 50.

distributing wires are made in a similar manner and are obvious from the figure.

The resultant mesh connection, made with two transformers is depicted in Fig. 51. The two primary coils of the two transformers are connected together on one side as shown, while the other two sides are connected to the transmission wires $T_1$ and $T_3$. $T_2$ is connected to the common junction point between the two primary coils $P_1$ and $P_2$. The connections on the low-tension or distribution side are exactly similar and easily followed from the diagram.

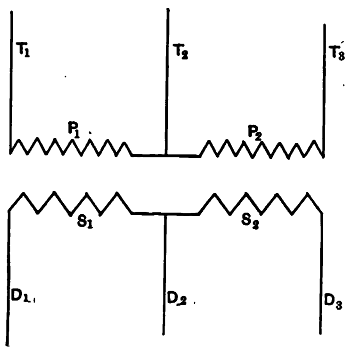



FIG. 51.

Each of these methods of connecting transformers has certain advantages, and the selection between the Y and the Δ seems to be largely a matter of personal preference rather than any real superiority. The resultant mesh

is not suitable for large powers and has its field of usefulness limited to supplying current to small motors, acting as a step-down transforming system.

In general, transformers for a given capacity and voltage are slightly cheaper and smaller when connected in Y fashion than when connected in mesh. On the other hand, the mesh connection has the advantage that if one of three transformers should break down it may be cut out and the operation of the plant would not be interrupted, the remaining two transformers working as resultant mesh-connected units. The two can, of course, deliver only about sixty-six per cent. of the required energy if they work at their normal rating, but by overloading them fifty per cent. and at the same time increasing to the highest possible amount the circulation of the cooling medium—whether air or water—the full load may probably be carried for one or two hours without injury to the overloaded transformers. For this reason the majority of plants have adopted the mesh connection.

A spare transformer should be kept in every power station ready to connect quickly in case of accident to any one of the operating transformers, and where they are all mounted on rollers, the removal of an injured transformer and the substitution of a spare one is accomplished expeditiously.

# CHAPTER IX.

## Transmission Conductors.

Transmission lines from the power station to the point of distribution, or to the town limits of a city, are always of bare uninsulated wire. Copper is generally employed, though aluminum is occasionally used.

The electrical problems which are involved comprise: (1) the determination of the sizes of wires and their relative positions to carry a given amount of energy over the distance from power station to point of distribution with a specified loss in energy; (2) the calculation of the necessary voltage at the power station to produce the required voltage at the receiving end of the line; (3) the computation of the energy required at the dynamo to deliver the given energy at the receiving end of the line; (4) the calculation of the sizes of dynamos and transformers necessary to deliver the specified energy; and (5) the protection of the line against lightning discharges. The mechanical problems are: (1) the method of supporting the wires on insulators; (2) the strains in wires, poles, pins, cross arms, and insulators which are allowable; (3) the proper organization of the pole line.

Taking up first the electrical problems, the examples given later show the methods employed to compute the first four mentioned.

*Standard wires.*—Wires are given arbitrary gauge numbers, a certain diameter and area corresponding to a given gauge number. In electrical computations the circular mil is the unit generally used. The number of circular mils (abbreviation, cir. mil) in a wire is equal to 1,000 times the diameter in inches squared. Thus a wire 0.25 inch in diameter has an area of $(0.25 \times 1000)^2 = 62{,}500$ circular mils. The *actual area* of a wire, in square inches, is equal to cir. mils $\times$ 0.7854 $\div$ 1,000,000. The following

wire table gives the gauge numbers of various sizes of copper wire, the diameter in inches, the number of cir. mils in each, the resistance in ohms per 1,000 feet, and the weight in pounds per 1,000 feet and per mile of soft-drawn copper:

BARE COPPER WIRE.

*Dimensions and Weights.*

| B. & S. gauge. | Circular mils. | Diameter, mils. | Pounds per 1,000 ft. | Pounds per mile. |
|---|---|---|---|---|
| 0000 | 211,600.00 | 460.000 | 639.33 | 3,375.66 |
| 000 | 167,802.93 | 409.640 | 507.01 | 2,677.01 |
| 00 | 133,079.04 | 364.800 | 402.09 | 2,123.03 |
| 0 | 105,534.02 | 324.860 | 318.86 | 1,683.58 |
| 1 | 83,694.49 | 289.300 | 252.88 | 1,335.21 |
| 2 | 66,373.22 | 257.630 | 200.54 | 1,058.85 |
| 3 | 52,633.54 | 229.420 | 159.03 | 839.68 |
| 4 | 41,742.58 | 204.310 | 126.12 | 665.91 |
| 5 | 33,102.16 | 181.940 | 100.01 | 528.05 |
| 6 | 26,250.48 | 162.020 | 79.32 | 418.81 |
| 7 | 20,816.72 | 144.280 | 62.90 | 332.11 |

BARE COPPER WIRE.

*Resistance Calculated at 70° F.*

| Ohms per 1,000 ft. | Ohms per 1,000 ft. | Ohms per mile. | Feet per ohm. | Ohms per pound. |
|---|---|---|---|---|
| 0000 | 0.04893 | 0.2621 | 20,147 | 0.0000776 |
| 000 | 0.06170 | 0.3306 | 15,972 | 0.0001234 |
| 00 | 0.07780 | 0.4168 | 12,668 | 0.0001962 |
| 0 | 0.09811 | 0.5251 | 10,055 | 0.0003114 |
| 1 | 0.1233 | 0.6627 | 7,968 | 0.0004960 |
| 2 | 0.1560 | 0.8360 | 6,316 | 0.0007894 |
| 3 | 0.1967 | 1.054 | 5,010 | 0.001254 |
| 4 | 0.2500 | 1.329 | 3,974 | 0.001994 |
| 5 | 0.3124 | 1.676 | 3,150 | 0.003173 |
| 6 | 0.4000 | 2.113 | 2,499 | 0.005043 |
| 7 | 0.5044 | 2.663 | 1,982 | 0.008013 |

Hard-drawn copper wire is frequently used where the spans are particularly long, because of its greater tensile strength. The

strength of soft-drawn copper is about 30,000 lbs. per square inch, while hard-drawn copper has a strength of double this, or 60,000 lbs. per square inch. The resistance of hard-drawn copper is about 5 per cent. greater than that of soft-drawn, and this percentage should be added to the tabular resistances as given, when hard-drawn copper is to be used.

*To compute the size of wire for a direct-current transmission* line, the allowable loss in the line must be assumed. The current in the line will be equal to the kilo-watts $\times$ 1,000 divided by the voltage, or $I = \frac{K.W. \times 1{,}000}{E}$. The size of wire required is equal to $\frac{2 \times D \times I \times 11}{E \times p}$ in circular mils. I is the current, in amperes, D is the distance of transmission in feet, E is the voltage at the receiving end of the line, $p$ is the loss allowed. The energy loss in a circuit is equal always to the resistance $\times$ (current)$^2$, or, loss $= I^2 R$. As an example, assume a 2-mile transmission ($= 2 \times 5{,}280 = 10{,}560$ feet), 250 K.W. to be delivered, the voltage at the receiving end to be 520 volts and the loss to be 10 per cent. Current $= \frac{250 \times 1000}{520} = 482$ amp. cir. mils. $= \frac{2 \times 10{,}560 \times 482 \times 11}{520 \times 0.10} = 2{,}$-150,000 cir. mils.

This nearly corresponds to 10 wires No. 0000 size as given in the table. The total weight per 1,000 feet is $640.5 \times 10 = 6{,}405$ lbs. The total length of wire is twice the distance of transmission $= 2 \times 10{,}560 = 21{,}120$ ft. Total weight of wire $= 21{,}120 \times 6{,}405 \div 1{,}000 = 135{,}000$ lbs. Add 3 per cent. for sag and joints $= 135{,}000 + 4{,}050 = 139{,}050$ lbs. The resistance of the circuit is one-tenth the resistance of a single circuit of No. 0000, there being ten wires in parallel. The resistance of a No. 0000 wire is about 0.05 ohm per 1,000 ft., and the resistance of a complete circuit of this size wire is, for this distance of transmission, $21{,}120 \times 0.05 = 1.056$ ohms. Resistance of 10 wires in parallel $= 1.056. \div 10 = 0.1056$ ohm.

Voltage drop in the line = amperes × ohms = 482 × 0.1056 = 51 volts.

Voltage at the generator = volts at receiving end + volts drop = 520 + 51 = 571 volts. Actual loss = $I^2 \times R = (482)^2 \times 0.105$ = 24,500 watts = 24.5 K.W. Per cent. less $= \frac{24.5}{250} = 9.82$ per cent.

If the K.W. capacity, the transmission distance, and the percentage loss be the same as before, but the voltage at the receiving end is 1,040 volts, or double the previously assumed value, the amount of copper required will be greatly reduced.

$$\text{Current} = \frac{250 \times 1{,}000}{1{,}040} = 240.5 \text{ amps.}$$

$$\text{Cir. mils.} = \frac{2 \times 10.560 \times 240.5. \times 11}{1{,}040 \times 0.10} = 537.500.$$

Compared with the cir. mils required for the previous case it is seen that this is just one-fourth the amount computed for a 520-volt pressure. As a matter of fact, *the amount of copper required is inversely as the square of the voltage of transmission.* This is the reason for the employment of high voltages on long transmission lines.

In very short lines the size of wire may be fixed, not by the drop in the line, but by the current-carrying capacity of the wire. A given size of wire can carry only a certain current, regardless of the drop or loss. The adjoining table gives the maximum currents allowable in various-size bare wires, to Brown and Sharpe gauge.

| Size of wire. | Allowable current. |
|---|---|
| 0000 | 400 amps. |
| 000 | 320 " |
| 00 | 270 " |
| 0 | 240 " |
| 1 | 190 " |
| 2 | 160 " |
| 3 | 135 " |
| 4 | 115 " |
| 5 | 92 " |
| 6 | 80 " |

*In alternating-current transmission lines* there is an inductive drop as well as the drop due to the resistance. This makes the total line drop greater than in the case of direct or continuous currents. The energy loss, however, is only that due

to the product of the square of the current flow and the resistance of the line, and is *not* equal to the drop multiplied by the current.

Take as an example a single-phase transmission of 750 K.W. to be delivered at the receiving end; voltage 10,000 volts; distance 14 miles; energy loss 10 per cent.; power factor 0.85; frequency 25 cycles per second; wires of circuit 36 inches apart; step-up and step-down transformers used having efficiencies of 97 per cent.

The apparent kilo-watts or K.V.A., delivered at the receiving end will be the actual K.W. divided by the power factor $= \frac{750}{0.85} =$ 882.3 K.V.A.

Actual energy delivered to the step-down transformers $= \frac{750}{0.97}$ $= 773$ K.W.

Apparent K.W. delivered to step-down transformers $= \frac{773}{0.85} =$ 910 K.V.A., which is the apparent energy transmitted over the line.

Current in the circuit $= \frac{910 \times 1,000}{10,000} = 91$ amps. Loss is to be 10 per cent. of the delivered energy $= 75$ K.W. $= 75,000$ watts.

Loss in watts also equals $I^2 \times R = (91)^2 \times R$.

$$(91)^2 \times R = 75 \text{ K.W.,} \quad R = \frac{75 \times 1,000}{(91)^2} = 9.08 \text{ ohms.}$$

The resistance per 1,000 feet is equal to the total resistance as found above, divided by the number of thousands of feet in the complete circuit, which is equal to *twice* the transmission distance, there being two wires to each circuit.

$$\text{Res. per 1,000 feet} = \frac{9.07}{2 \times 14 \times 5,280} \div 1,000 = \frac{9.07}{148} = 0.0613$$

ohm.

From the table, this corresponds most nearly to No. 000 wire, which should be adopted. The actual resistance of No. 000

is 0.0617 per 1,000 feet, which makes the resistance of the circuit = 148 × 0.0617 = 9.14 ohms, 148 being the length of the circuit in thousands of feet. The volts drop due to *resistance* will be equal to the current × the resistance = 91 × 9.14 = 831 volts.

To find the volts drop due to reactance consult the table following:

DISTANCE APART OF CONDUCTORS.*

| Size of Wire | Twelve inches | Eighteen inches | Twenty-four inches | Thirty inches | Thirty-six inches |
|---|---|---|---|---|---|
| 0000 | .193 | .212 | .225 | .235 | .244 |
| 000 | .199 | .217 | .230 | .241 | .249 |
| 00 | .204 | .222 | .236 | .246 | .254 |
| 0 | .209 | .228 | .241 | .251 | .259 |
| 1 | .214 | .233 | .246 | .256 | .265 |
| 2 | .220 | .238 | .252 | .262 | .270 |
| 3 | .225 | .244 | .257 | .267 | .275 |
| 4 | .230 | .249 | .262 | .272 | .281 |
| 5 | .236 | .254 | .268 | .278 | .286 |
| 6 | .241 | .260 | .272 | .283 | .291 |

* Reactance volts in 1,000 feet of line (= 2,000 feet of wire) for one ampere at 7,200 alternations per minute (60 cycles per second) for the distance given between centres of conductors.

The values given in this table are for frequencies of 60 cycles per second. To find the factor for other frequencies, multiply the factor in the table by the frequency, and divide the product by 60. The result will be the reactance factor for the desired frequency.

From the table the reactance volts per 1,000 feet of transmission distance (= 2,000 feet of circuit) for No. 000 wires placed 36 inches apart is 0.249 volt for each ampere flowing when the frequency is 60 cycles per second. Therefore, the reactance volts for the case under consideration and basis of 60 cycles would be (14 × 5,280 ÷ 1,000) × 91 × 0.249 = 74 × 91 × 0.249 = 1,678 volts. The factor 0.249 is, however, for a frequency of 60 cycles, and the frequency of the system under discussion is 25 cycles. Therefore the above value must be changed to one proportional to the frequency, and the actual volts will be, $\frac{1,678 \times 25}{60} = 700$ volts.

The line drop is equal to the square root of the sum of the resistance drop squared and the reactance volts squared, or drop $= \sqrt{(\text{res. volts})^2 + (\text{react. volts})^2} = \sqrt{(831)^2 + (700)^2} = 1{,}086$ volts.

The energy loss $= I^2 R = (91)^2 \times 9.14 = 75.8$ K.W. $= 10.1$ per cent. of the delivered power.

Apparent energy loss in line = volts drop × line current = 1,086 × 91 = 98.8 K.V.A.

Actual energy to be delivered by the step-up transformers is that delivered to the step-down transformers + loss in the line = 773 K.W. + 75.8 K.W. = 848.8 K.W.

The apparent energy delivered by the step-up transformers is equal to the apparent energy delivered to the step-down transformers + apparent energy lost in the line = 910 + 98.8 = 1,008.8 K.V.A.

Actual energy delivered to the step-up transformers is equal to their output divided by their efficiency—97 per cent. in this case:
Energy $= \dfrac{848.8}{0.97} = 875$ K.W., which is the actual energy the dynamo must deliver to the step-up transformers.

The apparent energy delivered to the step-up transformers is equal to the apparent energy delivered by them to the line, divided by the transformer efficiency $= \dfrac{1{,}008.8}{0.97} = 1{,}040$ K.V.A., which is the required dynamo capacity.

The computations, then, summarized, are as follows:

Size of generating equipment.........1,040 K. V. A.
Size of step-up transformers........1,008.8 K. V. A.
Size of step-down transformers.........910 K. V. A.
Size of line wire, No. 000 B. & S. gauge.
Total losses in system from generator to motors = 875—750..........................125 K. W.
Current in line........................91 amps.

Voltage of step-up transformer = 10,000 + 1,086 = 11,086 volts.
The power required at the turbine shaft, if the dynamo effi-

ciency is 94 per cent. will be equal to the actual energy delivered by the dynamo divided by its efficiency. This is equal to

$$\frac{875}{0.94}=831 \text{ K.W.}=1,246 \text{ H.P.}$$

The size of the turbine should be increased by about 20 per cent. to take care of speed regulation and wear. This would make the turbine power 1,506 H.P. If the efficiency of the turbine is 80 per cent., the gross hydraulic power necessary to deliver the 750 K.W. at the motors is $\frac{1,246}{.80}=1,557$ H.P.

The plant would be divided into three units. Each turbine would have a capacity of 500 H.P., making the aggregate 1,500 H.P. Each dynamo would give 350 K.V.A., making 1,050 K.V.A. total. There would be four transformers at the power station of 250 K.V.A. each, giving a station-transformer capacity of 1,000 K.V.A. The receiving transformers would be three in number, each of 300 K.V.A. capacity, making a total of 900 K.V.A., all of which figures correspond very closely to the actual computed requirements and which are obtained with standard apparatus.

*The usual transmission is three-phase,* a circuit being made up of three wires of equal size and resistance. There are two methods of computation which may be followed. One is to divide the delivered energy by 2, and assume a single-phase system supplying this half the total energy. On this basis, compute the size of wire, the resistance drop, the reactance drop, and total drop as given in preceding example. Each of the three wires of the three-phase circuit will then be the same size as that computed, and the drop will be the same. The more complete method, is, however, fully indicated in the following example:

Assume a three-phase system to deliver 8,000 K.W. to a distribution circuit fed from a high-tension transmission line. Power factor of the distribution circuit = 0.88; voltage of transmission at receiving end = 25,000 volts; distance 35 miles ( = 184,500 feet); frequency 25 cycles; energy loss in transmission line 8 per cent. of delivered power; dynamo efficiency 95 per cent.;

transformer efficiency 97 per cent.; wires 24 inches apart, arranged in triangular relationship (see Fig. 52).

Actual energy delivered by step-down transformer = 8,000 K.W.

Apparent energy = actual ÷ power factor $= \frac{8,000}{0.88} = 9091$ K.V.A.

Energy input to step-down transformers $= \frac{8,000}{0.97} = 8,247$ K.W. actual.

Apparent energy input $= \frac{8,247}{\text{power factor}} = \frac{8,247}{0.88} = 9,361$ K.V.A.

Energy loss in line = 8 per cent. of 8,000 K.W. = 640 K.W.

The actual energy transmitted over the line *per wire* is one-third of the total $= \frac{8,247}{3} = 2,749$ K.W.

The apparent energy transmitted over the line per wire is $\frac{9,361}{3}$ = 3,120 K.V.A.

In any three-phase system the *effective* voltage is equal to the line voltage divided by $\sqrt{3}$ or 1.732.

The effective voltage, therefore, of this system is $\frac{25,000}{1.732}$ = 14,400 volts. The line current per wire = apparent energy per wire delivered to the step-down transformers divided by the effective volts, which for this case $= \frac{3,120 \times 1,000}{14.400} = 217$ amperes.

$I^2 R$ = line loss = 640 K.W. total and per phase $= \frac{640}{3} = 213.3$ K.W.

$$R = \frac{213.3 \times 1,000}{I^2} = \frac{213.3 \times 1,000}{(217)^2} = 4.54 \text{ ohms.}$$

This is the total resistance of one wire, which in computing three-phase lines is the length always taken instead of double the length of transmission. This assumption of the single distance is

compensated for by reducing the line voltage in the calculations in the ratio of 1 to 1.732.

Length of the single wire = 184,500 feet.

Resistance of wire per 1,000 ft. $= \frac{4.54}{184.5} = 0.0246$ ohm.

This resistance is less than that of a No. 0000 wire, and consequently should be divided into two separate circuits at least. The current per wire will thus be halved, and the resistance per wire correspondingly increased.

For two circuits:

$$I = \frac{217}{2} = 108.5 \text{ amperes per wire.}$$

$$I^2 R = \frac{213.3 \text{ K.W.}}{2} = 106.6 \text{ K.W. per wire.}$$

$$R = \frac{106.6 \times 10{,}000}{(108.5)^2} = 9.08 \text{ ohms per wire.}$$

Resistance per 1,000 feet of wire $= \frac{9.08}{184.5} = 0.0492$. This corresponds most nearly to a No. 0000 wire. Adopting this, the resistance per 1,000 feet of wire is 0.04893 and its total resistance is $0.04893 \times 184.5 = 9$ ohms.

Energy loss per wire $= I^2 R = (108.5)^2 \times 9 = 106.000$ watts.

Energy loss per circuit $= 3 \times 106 = 318$ K.W.

Energy loss both circuits $= 2 \times 318 = 636$ K.W.

Resistance drop per wire $= I R = 108.5 \times 9 = 976$ volts.

Reactance volts, computed by factor from table as follows:

Reactance volts per 1,000 feet of transmission distance for each ampere of current in a wire No. 0000 size, with a separation of 24 inches and a frequency of 60 cycles is, from the table, 0.225.

Reactance volts per 1,000 ft. for 108.5 amperes $= 108.5 \times 0.225 = 24.2$ volts. Reactance volts for 184.500 ft. $= 184.5 \times 24.2 = 4{,}460$ volts. Reactance volts for 25 cycles $= \frac{4{,}460}{60} \times 25 = 1{,}860$ volts.

This value is for a *double* circuit, and in calculating a three-phase transmission only one leg is considered. Obviously, the reactance volts are half the amount per leg of the reactance volts for a double circuit. Hence reactance volts, actual will be $\frac{1,860}{2} = 930$ volts.

Volts drop $= \sqrt{(\text{Resistance drop})^2 + (\text{Reactance volts})^2}$; in this case $= \sqrt{(976)^2 + (930)^2} \doteq 1,272$ volts.

Apparent energy lost in line $= 1,272 \times 108.5 = 138$ K.V.A. per wire. Total for the six wires of the two circuits is equal to $6 \times 138 = 828$ K.V.A.

Actual energy delivered by the step-up transformers to the line = actual energy delivered to step-down transformers + line loss $= 8,247 + 636 = 8,883$ K.W.

Apparent energy delivered by step-up transformers is the apparent energy delivered to the step-down transformers + apparent energy of the line $= 9,361 + 828 = 10,189$ K.V.A.

Actual energy delivered to step-up transformers = energy given out by them divided by their efficiency $= \frac{8,883}{0.97} = 9,100$ K.W.

The apparent energy input to the step-up transformers = apparent energy delivered by them divided by their efficiency = $\frac{10,189}{0.97} = 10,500$ K.V.A.

This last is, of course, the apparent energy supplied by the generators and must be the generating capacity, while the actual energy delivered by the generators is 9,100 K.W.

Summarizing the computations:

| | |
|---|---|
| Size of generating equipment | 10,500 K.V.A. |
| Size of step-up transformers | 10,189 K.V.A. |
| Size of step-down transformers | 9,091 K.V.A. |
| Line wire—two circuits of three wires each, size B. & S. gauge | No. 0000 |

Total loss in system from generator to motors = 9,100 — 8,000. . . . . . . . . . . . . . . . 1,100 K.W.
Current in each wire. . . . . . . . . . . . . . . . . . . . . 108.5 amps.

Effective voltage of step-up transformers = 14,400 + 1,272 = 15,672.

Voltage between wires at step-up transformers = 15,672 × 1.732 = 27,200.

If two pole lines each carrying two circuits were run, the load would thus be divided among four circuits, and the size of each wire would be halved. The resistance drop would be the same, but the reactance drop would be diminished about half because only half the current, as before computed, would flow in each line, and the calculations show that the amount of the reactance volts depends on the current flow. Also, a wire as large as No. 0000 is heavy and difficult to erect. Therefore, for this and other practical reasons that make desirable a double pole line, it would be better to run four circuits, two on each pole line.

The turbine power required is based on the actual energy—9,100 K.W.—delivered by the dynamo, and is computed exactly as in the preceding example.

When step-up transformers are omitted, the calculation is somewhat simplified. The use of these transformers is a question which must be settled for each case. Their advantages are: the use of a low-tension dynamo, the use of low-voltage switching and manipulating apparatus, confining the high-voltage currents in an iron case filled with insulating oil, and decreased cost of line copper. Their disadvantages are: initial cost, the addition of a weak point in the circuit, and the continual power loss which attends their operation.

Frequently, it is better to use a 6,600-volt generator, omit the transformers, and with the money thus saved add to the quantity of copper or even spend a little more for the wire. It is better to invest money in a staple commodity like copper, which does not depreciate and always has a market value, than to invest

in electrical apparatus, when the differences in initial cost and operating losses are slight. The question of the transmission system is more a financial than an electrical problem, and must be solved on the former basis.

The foregoing calculations may be summarized in formulas as follows:

Let $E$ = voltage at receiving end between wires.
" $E_0$ = voltage at station end between wires.
" $I$ = current in line.
" $F$ = power factor.
" $D$ = distance of transmission in thousands of feet = (dist. in miles × 5,280 ÷ 1,000).
" $N$ = frequency of system in cycles per second.
$M$ = efficiency of step-down transformers.
" $M_1$ = efficiency of step-up transformers.
" $P$ = percentage energy loss in the line ÷ 100, referred to delivered power.
" $R$ = resistance of each wire of a circuit per 1,000 feet.
" $S$ = reactance volts in line.
" K.W. = actual energy delivered.

*Then for a single-phase system:*

$$\text{Energy to step-down transformers} = \frac{\text{K.W.}}{M} \quad \ldots\ldots (1)$$

$$\text{Apparent energy to step-down transformers} = \frac{\text{K.W.}}{M \times F} \quad \ldots\ldots (2)$$

$$I = \frac{\text{K.W.} \times 1{,}000}{M \times F \times E} \quad \ldots\ldots (3)$$

$$R = \frac{\text{K.W.} \times 1{,}000 \times P}{2 \times D \times I^2} \text{ (in ohms per 1,000 feet of wire)} \quad \ldots\ldots (4)$$

$$\text{Resistance drop} = I \times R \times 2D \quad \ldots\ldots (5)$$

$$\text{Reactance drop} = \frac{Q \times I \times D \times N}{60} \quad \ldots\ldots (6)$$

$Q$ being the factor from the table for the size of wire adopted and the distance of separation between wires.

Line drop $=\sqrt{(\text{resist. drop})^2 + (\text{react. drop})^2}$............(7)

Energy delivered in K.W. by step-up transformers

$$=\frac{\text{K.W.}}{\text{M}}+\text{I}^2\times\text{R}\times 2\text{D}\ldots\ldots(8)$$

Energy delivered in K.W. to step-up transformers = energy delivered by generators $=\dfrac{\text{K.W.}}{\text{M}\times\text{M}_1}+\dfrac{\text{I}^2\times\text{R}\times 2\text{D}}{\text{M}_1\times 1{,}000}$.........(9)

Apparent energy in K.W. delivered by step-up transformers

$$=\frac{\text{K.W.}}{\text{M}\times\text{F}}+\frac{\text{I}\times\text{line drop}}{1{,}000}\ldots\ldots(10)$$

Apparent energy delivered by generators to step-up transformers $=\dfrac{\text{K.W.}}{\text{M}\times\text{M}_1\times\text{F}}+\dfrac{\text{I}\times\text{line drop}}{1{,}000\times\text{M}_1}$....................(11)

E. = E + line drop (approximately)....................(12)

*For three-phase lines the formulas become:*

Energy to step-down transformers $=\dfrac{\text{K.W.}}{\text{M}}$..............(1)

Apparent energy to step-down transformers $=\dfrac{\text{K.W.}}{\text{M}\times\text{F}}$ ....(2)

$\text{I}=\dfrac{\text{K.W.}\times 1{,}000}{3\times\text{M}\times\text{F}\times\text{E}_e}$ = in which $\text{E}_e=\dfrac{\text{E}}{1.732}$ = effective voltage.

$$\text{R}=\frac{\text{K.W.}\times 1{,}000\times\text{P}}{3\times\text{D}\times\text{I}^2}\ldots\ldots(14)$$

This result is in ohms per 1,000 feet *per wire.*

Resistance drop = I × R × D..........................(15)

Reactance drop $=\dfrac{\text{Q}\times\text{I}\times\text{D}\times\text{N}}{120}$....................(16)

Line drop $=\sqrt{(\text{resist. drop})^2 + (\text{reac. drop})^2}$............(17)

Energy delivered by step-up transformers

$$=\frac{\text{K.W.}}{\text{M}}+\frac{3\,(\text{I}^2\times\text{R}\times\text{D})}{1{,}000}\ldots\ldots(18)$$

Energy delivered to step-up transformers

$$= \frac{\text{K.W.}}{M \times M_1} + \frac{3\,(I^2 \times R \times D)}{M_1 \times 1{,}000} \quad\ldots\ldots\ldots\ldots(19)$$

Apparent energy delivered by step-up transformers

$$= \frac{\text{K.W.}}{M \times F} + \frac{3\,(I \times \text{line drop})}{1{,}000} \quad\ldots\ldots\ldots\ldots(20)$$

Apparent energy delivered to step-up transformers

$$= \frac{\text{K.W.}}{M \times M_1 \times F} + \frac{3\,(I \times \text{line drop})}{1{,}000 \times M_1} \quad\ldots\ldots\ldots\ldots(21)$$

$$E_0 = E + \text{line drop (approximately)} \quad\ldots\ldots\ldots\ldots(12)$$

All the foregoing are simply close practical approximations which are as near to the exact figures as standard sizes of wire and electrical apparatus make it necessary to come. The effect of capacity has been neglected as it is negligible except in very long lines—say 50 miles and above—unless the separate wires of the circuit are placed close together, and good practice prevents this closeness of conductors. The effect of the capacity current is to reduce slightly the apparent energy and the line current. It has no effect on the actual energy delivered.

If systems are installed on the basis of the foregoing formulas and the lines are long, the only noticeable result will be a slightly less line drop and less heating of generators and transformers than the computations show.

*Aluminum Conductors.* Aluminum is now used to a limited extent for transmission lines. Its weight is 0.3 that of copper for a given size and length of wire. Its conductivity is 0.63 that of copper. Therefore, for a given resistance per mile, the area of an aluminum wire should be $\frac{1}{0.63} = 1.587$ times the area of a copper wire. As the area is proportional to the square of the diameter, the diameter of an aluminum wire must be 26 per cent. greater than the diameter of a copper wire for equivalent conductivity. The weight of aluminum compared to that of copper for a given conductivity

is equal to $\frac{0.3}{0.63}=0.476$; that is, $47\frac{1}{2}$ pounds of aluminum are equal in conductivity to 100 pounds of copper. Therefore, the price which may be paid for aluminum to produce a given conductivity is $\frac{1}{0.476}=2.1$ times the price of copper. It should, however, be bought at a lower price than $2.1 \times$ cost of copper, as it is more difficult to join together and more trouble to put in place, owing to its comparative brittleness and softness. At 1.75 times the price of copper it will pay to substitute aluminum.

The formulas and methods of computation before given for transmission lines apply equally to aluminum and copper conductors. The size of the copper wire is taken from the table to correspond to the computed resistance. By adding 26 per cent. to its diameter, or 58 per cent. to the circular mils as given for the copper conductor, the size of the equivalent aluminum wire is found. Thus if the computed resistance is .0976 per 1,000 feet, this corresponds (nearly) to a No. 0 copper wire. The diameter of a No. 0 wire is 0.340 inch. Adding 26 per cent. this becomes 0.4384, which corresponds (nearly) to a 000 wire. Likewise, the circular mils of a No. 0 wire are 115,600. Adding 58 per cent. to this, the cir. mils are 182,600 which nearly corresponds to No. 000 wire. The computed size for aluminum is to be used for taking the reactance volts drop factor from the table.

Solid aluminum wires are never used. Conductors of this material must always be stranded owing to its unreliability as to tensile strength in occasional spots. Also its brittleness makes the stranded conductors desirable.

*Arrangement of Wires.* In the case of several single-phase circuits, all fed from the same source and working in parallel, the wires may be arranged on the cross-arms in any convenient manner. If, however, two separate circuits fed from different dynamos run on the same pole line, the wires of each circuit should be placed as close together as conditions will allow, and the two

circuits separated as much as possible. This is to avoid the effect of mutual inductance between the two circuits which will cause pulsation in voltage that will seriously interfere with any lighting service.

A better way is by transposing the wires, as shown in Fig. 52, which is a plan view. As indicated, the wires of one circuit run parallel, all the way from the station to the point of distribution, while the other circuit has the position of its wires transposed at the middle point of the line.

In three-phase systems, the wires are usually placed in such positions that lines joining their centres form an equilateral triangle, as shown in Fig. 53. Where a single circuit is placed on one pole,

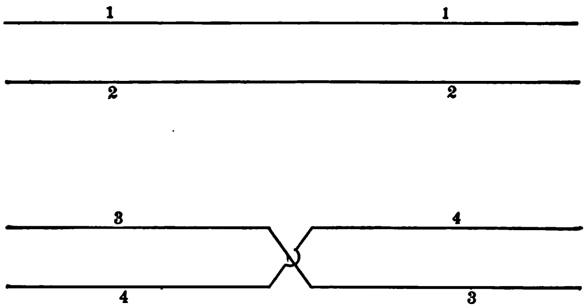



FIG. 52.

no transposition is necessary. If two circuits be put on one pole, the wires of one circuit should run parallel, the wires of the other circuit being transposed *twice* in the entire length of circuit, the points of transposition being at one-third and at two-thirds the total distance from station to distribution point.

In Fig. 54 the upper two circuits illustrate this arrangement. Fig. 55 shows the usual way of placing two circuits on a single pole. If a third circuit be placed on the same pole line with the first two, it must be transposed three times in the same distance that the second circuit is transposed once; or the distance apart of the transposition points is one-ninth the total length of the line. The lowest circuit shown in Fig. 54 gives this transposition as related to the other two circuits.

All the foregoing is based on the arrangement of the wires of each circuit, so that any wire is the same distance from either of the other two, *i.e.*, at the apexes of an equilateral triangle. If, however, the three wires of a circuit are all placed on the same cross-arm, so that they lie in the same plane, the wires of each cir-

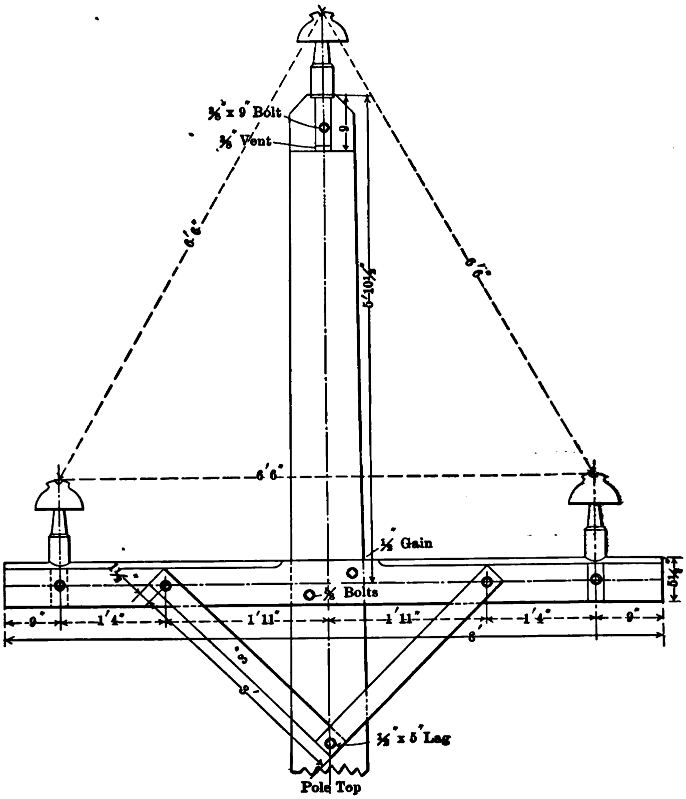



FIG. 53.

cuit must be transposed. The transposition for one circuit on a pole is that of the middle circuit shown in Fig. 54; that is, two transpositions in the length of the transmission, one at one-third, the other at two-thirds the distance from the power station. A second

circuit on the same pole would be transposed like the lowermost circuit shown in Fig. 54; *i.e.*, a transposition at each one-ninth of the transmission length.

A certain tension should be put on the wires in stringing them

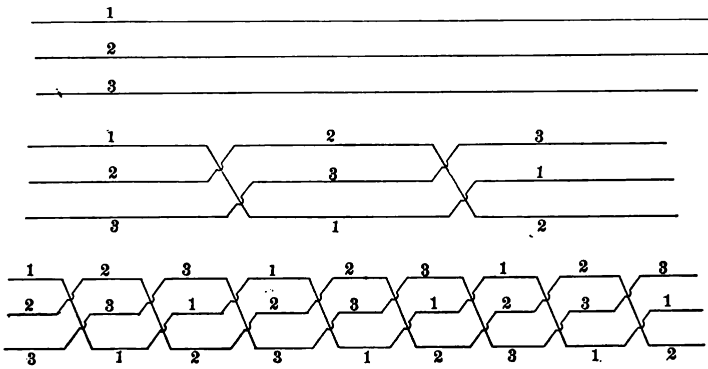



Fig. 54.

on the poles, and it should be just great enough to give a definite amount of sag, or dip below the horizontal. The sag is dependent on

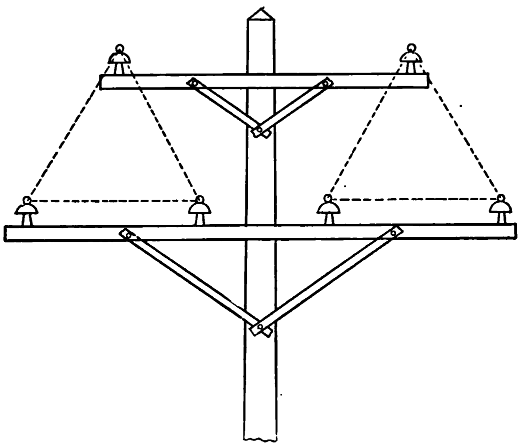


Fig. 55.

the length between spans and the temperature at the time of setting.

A good rule is to allow a sag equal to 0.0155 × length between

spans for a temperature of 60° F. Increase or diminish the amount of sag thus found $7\frac{1}{2}$ per cent. for each 10° F. above or below 60°. Thus, if spans are 200 feet, the sag would be $200 \times 0.0155 = 3.10$ feet for 60° F. If the temperature at the time of erecting were 90° F., the sag would be increased by a percentage $= (90 - 60) \times 7\frac{1}{2} = 22\frac{1}{2}$ per cent.

$22\frac{1}{2}$ per cent. of $3.10 = 0.6975$. Sag actual $= 3.10 + 0.6975 = 3.795$, say 3.8 feet = 3 feet $9\frac{1}{2}$ inches.

The spacing apart of wires varies from 36 inches in short spans—say up to 150 feet—to 78 inches in long spans and with high voltages. Increasing the distance of separation increases the inductive drop, thereby increasing the size of generators and the line losses, while if placed too near together, the chance of swaying bringing the wires in contact, or the possibility of sudden high potentials, due to surging, causing a break-down at the cross-arms, is increased.

Roughly, in transmissions up to 10,000 volts the distance should be 30 to 40 inches, up to 30,000 volts the separation should be 48 to 60 inches, and above 30,000 volts the distance should be about 66 to 72 inches. These distances vary somewhat with the length of span.

# CHAPTER X.

## Pole Line and Accessories.

### *Supporting Poles.*

There is considerable controversy as to the best method of supporting the transmission wires. In all electrical lines worked at high voltages, every point of support is a possible source of trouble from leakage or break-down of the insulators. On this account the supports should be placed far apart.

On the other hand, the greater the distance between supports, the greater is the strain on the wires and insulators, the sag is increased, the wires must be placed farther apart to prevent touching when swayed by winds, and this increases the inductive drop. Therefore, the spacing of poles or towers to carry the wires must be a compromise between these two opposing sets of conditions.

In cold climates, the poles must be nearer together than in milder latitudes because of the possibility of an ice-coating forming on the wires. This may become so thick as to form a continuous cylinder having a diameter as much as 1½ inches greater than that of the wire itself. Such a mass of ice adds greatly to the weight carried on the poles, and may cause breaking of insulator pins or rupture of the wire itself.

The standard practice in the Eastern States, for pole lines, is about 150-foot spacing, or 36 poles per mile. In California and other Western States having mild temperatures, spans up to 500 feet are being used. These conductor lengths are too heavy to carry on poles, and steel towers are substituted, which are made of ordinary structural-steel shapes, and weigh about 1,400 pounds for a 45-foot height, with cross-arms made of wrought-iron pipe, and proper provision for receiving insulator pins. Their present cost is

about $3\frac{1}{2}$ cents per pound, or a 45-foot tower placed in position costs about \$50.00. There are 21 of these in two miles, making the cost \$1,050.00, or \$525.00 per mile. Wooden poles of the same height and proper diameter cost with cross-arms about \$7.50 each, set. Thirty-six of these for one mile cost, therefore, \$270.00, or about half the cost of the steel towers. The poles, however, require replacing within from 10 to 12 years, while the towers will last indefinitely. The towers must be painted once every 18 to 20 months, which is an item of maintenance expense. Also, they allow the wires to ground if an insulator should fail. In their favor are their durability and the distance apart of the insulators. Their chief drawback is the first cost; and in spite of theory and calculations, the main object in view when installing a transmission plant is to get it into efficient and reliable operating form as cheaply and expeditiously as possible. After dividends have been declared a few years, and the wooden poles need to be replaced, the steel towers, bought with earnings of the plant, may be erected.

When long spans are adopted, hard-drawn copper wires should be used.

Poles may be of nearly any kind of growth that is strong, reasonably straight, and resists rot. White cedar, yellow pine, locust, chestnut, cypress, and spruce have all been used.

White cedar and chestnut poles have an average life of twelve years, pine eight, cypress fourteen, and red cedar eighteen years. Concrete poles reinforced by iron bars have been lately tried and found to be satisfactory in every respect except the initial cost, which is about three times that of wood poles.

The height of poles depends on local conditions. In open country, on a private right of way, the lowest wires should be at least 28 feet above the ground. In passing over roadways or populated districts the wires should be at least 45 feet above the ground, and 55 feet is a better height.

The length of poles should be about $12\frac{1}{2}$ per cent. greater than the height above ground, which excess is the length to be set in the ground. In soft marshy earths the depth in the ground should

be greater. No pole should be set with less than four feet in the ground.

Poles must be amply proportioned to carry the various loads imposed on them by the pull of the wire, due to its weight between spans, the weight of the largest possible ice-coating, the wind pressure, and the strain set up when the direction of the wires is changed producing an unbalanced pull on the poles. In the last case the pole is braced by heavy guy wires running from a point near the top of the pole to a short heavy stub and fixed firmly in the ground at some distance from the pole.

The following proportions are usual in practice:

Poles 35 feet high should have a circumference of 18 inches at the top, 45-foot poles 22 inches, 55-foot poles 24 inches.

In setting poles, the butts should be given a good coating of hot pitch or asphaltum, if they have been previously seasoned. Green poles should not be so coated, however, as it hastens their decay by imprisoning the moisture in an impervious covering. When covered with pitch, the coating should extend up at least a foot above the ground line.

In many cases, two separate pole lines have been erected each carrying its own circuits, so that, in event of accident to either, it can be switched out of service and repairs made while the other line carries the load, with a greater drop and line loss. This is, of course, an excellent arrangement, but its cost is high and a duplicate pole line should more properly be paid for by earnings produced by a single line.

Where the line passes through wooded country, the trees on either side must be cut down, so that no tree is left near enough to the line to reach it if uprooted or broken off. Also duplicate pole lines should be set apart far enough to prevent a broken pole on either line from falling against the other line.

*Cross-arms.* These may be of any of the woods which are strong and durable. Yellow pine is used more than any other material.

The usual cross-arm is a rectangular bar varying from $2\frac{1}{2} \times$

$3\frac{1}{2}$ to $4\frac{1}{2} \times 6$ inches in cross-section. The upper surfaces are beveled to allow water to run off freely.

They are set in shallow recesses or gains cut in the pole, and bolted on with two bolts each of from $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter, which pass through pole and cross-arm and are fastened with nuts. Large washers are put on the bolt at each end to make a good bearing surface against the wood. The arms are further fastened by bracing, the usual form of brace being a pair of flat galvanized iron strips about $\frac{1}{4} \times 1\frac{1}{4}$ inches in cross-section, with a hole in each end. One $\frac{1}{2} \times 5$ inch lag screw passing through the holes in the two braces, laid one on top of the other, holds these ends to the pole. The other ends are spread apart and fasten to the cross-arm with a $\frac{1}{2} \times 3$ inch lag screw through each.

A pole head for a three-phase circuit is shown in Fig. 52 and gives these details.

Usually, cross-arms are boiled in linseed oil for several hours to preserve them, and then painted. In any case they should be painted with a good weather-proof paint. One of the best investments is to use large, strong cross-arms. The large sizes cost but little more than the smaller ones, and one of the weak points is at the cross-arms. Never use a size smaller than $3\frac{1}{2} \times 4\frac{1}{2}$ inches.

*Insulators*. There are two prime requisites for any insulator; it must have a high insulating quality and it must possess mechanical strength. All the strains in the line, the weight of the wires, or the stresses set up by wind and swaying must be taken by the insulators, and the element of mechanical strength is the really important factor.

For this reason, porcelain insulators are preferable to glass ones, provided the porcelain is high grade and well burned until it is vitreous throughout.

Glass insulators, however, have been used in high-tension transmission work up to 40,000 volts with marked success, and their lower cost makes them attractive.

The controversy of glass *versus* porcelain which endured so long has practically been settled in favor of porcelain, due no doubt to

improved methods of manufacture and the resulting betterment of the quality of the latter. Some engineers still use glass, however, and find them satisfactory.

Types of insulators are many and various, and their description here would be out of place.

Never put an insulator in place on a high-tension line without first testing it for dielectric strength. The test is standard and simple.

Invert a number of insulators in a pan of salt water, of sufficient depth to cover about seven-eighths of the insulator. Fill the upturned pin opening in the centre of the insulator about half full of salt water. Be sure that the insulator is fairly dry from the surface of the water in the pan to the water in the inner hollow of the insulator, by wiping off spilled water. Put a metallic pin or a carbon rod—an ordinary arc-lamp carbon does very well—into each of the pin openings so that it reaches to the bottom. Connect the pan to one terminal of the secondary of a transformer, and the rods or pins to the other terminal. The transformer should give a potential of three to four times that of the line the insulators will be used on. Switch on the current to the primary of the transformer. Defective insulators will be ruptured and their pressure indicated by vicious arcing. A fuse must be placed in the circuit to the primary of the transformer to protect it when the insulators give way.

To test the quality of the porcelain in insulators, break one in pieces. Put red ink on the fractures and allow it to dry, then wash the fracture thoroughly. If the ink washes off clean, the porcelain may be considered as good quality and without absorptive power. If the ink does not wash off, the porcelain is not suitable for insulating purposes.

The cost of high-tension porcelain insulators runs from 50 cents to $2.00 each. Glass insulators cost from 10 cents to 40 cents each. The use of glass should be limited to voltages of 30,000 volts or under.

*Insulator Pins.* These are made of both wood and iron. Various kinds of woods are used, but locust is the best.

The pins must be strong enough to take the various line strains before set forth. Experience shows that the standard pin, having a $1\frac{1}{2}$ inch diameter at the shank (*i.e.*, the lower end, which fastens into the cross-arm), is not sufficiently strong to carry the large wires over long spans that are now encountered in transmission work. No wooden pin should be less in diameter than 2 inches at the shank; and if the length of the pin above the cross-arm—that is, exclusive of the shank—should exceed 11 inches, the diameter should be made greater. In fact, $2\frac{3}{4}$ inches diameter for pins 16 inches long is not excessive.

It is, of course, understood that the cross-arms are of proper thickness, which is 2 inches greater than the diameter of the pin, giving not less than 1 inch of stock on either side of the pinhole. The length of the shank should be the same as the depth of the cross-arm, so that the shank passes through the cross-arm from top to bottom. The pins are held in their sockets by passing a $\frac{3}{8}$-inch coach bolt through the cross-arm and each pin shank.

Wood pins should always be boiled in linseed oil or stearic acid for several hours before putting in position.

There are several varieties of iron pins. In one form the pin is made of $\frac{5}{8}$-inch rods threaded to screw into a cast-iron upper piece, which latter has approximately the dimensions of a wooden pin. The insulator screws onto this casting.

Another form comprises a hollow porcelain shape, having proper dimensions to fit into the insulator, an iron pin passing through the porcelain piece and through the cross-arm.

Wooden pins are subject to deterioration from charring, burning, and softening. The first two come from leakage currents which manage to find a path due to the accumulation of dust, dirt and sometimes moisture. Softening is produced by the "brush discharge" from the line, which produces minute quantities of nitric acid. This eats into the wood and destroys it. Iron pins are not subject to any of these troubles, and their superior strength would seem to make them the best form of pin. They, however, lack the insulating quality of the wooden pin, they are more con-

ducive to leakage currents and insulator break-downs; are more expensive to install, and tend to loosen in their sockets if the cross-arms are of wood. Therefore, the wooden pins are used on the majority of transmission lines in this country. The use of iron pins, however, is increasing, due to the better grade of insulators now obtainable.

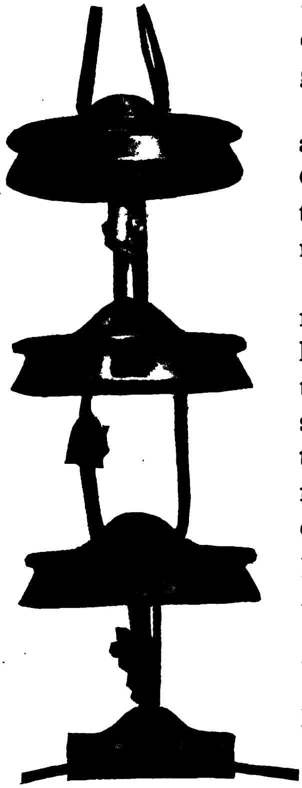


FIG. 56.

Insulators set on iron pins should always be held in place with cement. Ordinary Portland cement, made to a thick paste with water is very good, or melted sulphur may be used.

A recent method of supporting transmission conductors eliminates the insulator pins, and suspends the wires below the cross-arms by means of insulating suspension links. These links are of two types, comprising those which are meant to hang vertically and those which catch the end of a wire and hold it to the pole and have a horizontal position when installed.

Fig. 56 shows a series of three of these vertical suspension links, while Fig. 57 shows three horizontally stretched links, Fig. 58 being a section through one of the latter which shows the method of constructing these insulators. They are made of porcelain discs having spherical-shaped portions in their centres. Two semicircular tunnels, at right angles to each other and interlinked, are formed in the spherical portion, one tunnel passing in one from one side of the disc and back out the same side, while the other tunnel passes in from the opposite side and back out on the same side it enters. The construction is clear from

the figures, and it is obvious that the strain on the porcelain is compressive.

Figs. 59 and 60 show the methods of using these link insulators. Fig. 59 shows the suspension of a wire hanging from a cross-arm

FIG. 57.

and below it. Fig. 60 shows the horizontal or tension link insulators attached to a supporting tower, and to which the ends of the transmission wire are fastened. The wires are in the latter case practically "dead-ended," but the line is made continuous by a loose connecting wire which joins the two conductors as indicated in the figure. The preferred practice is to use the tension insulators about every mile, and suspension insulators at the intermediate supporting points. This produces independent sections of wire, each one mile in length, supported at proper intervals.

FIG. 58

With these insulators any practical attainable voltage may be used, as each disc is capable of carrying 25,000 volts with a factor of safety against arcing around from one face to the other of about 2½. For higher voltages the insulators are simply placed in

series, two being required for 50,000 volts or four for 100,000 volts. Owing to their great strength which enables each insulator to support a load of three tons without rupture, the weight of wire

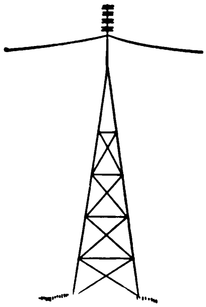


FIG. 59.

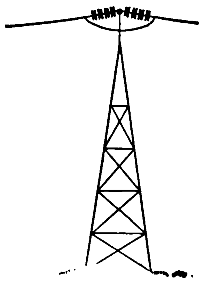


FIG. 60.

between spans, and consequently the length of spans, may be very great. Ten poles or towers per mile is the spacing that has been adopted for one transmission line using these insulators, and spans up to 1,000 feet in length may be safely carried.

FIG. 61.

The diameter of the discs is 10 inches for 25,000 volt units and 6½ inches for 12,000 volt units. If the porcelain should crush or be otherwise shattered, the line does not fall, as the interlinked wire loops passing through the tunnels in the porcelain simply come together and take the strain. Fig. 61 shows a broken insulator and the resulting linking together of the wire loops. Fig. 62 shows in outline the arrangement of two three-phase circuits on a tower, the voltage being 100,000. The wires are not arranged triangularly and therefore must be transposed,

as directed in the previous chapter, in order to balance static and inductive effects.

Fig. 63 shows the general layout of a two-circuit, three-phase line for 80,000 volts, the wires being placed in a right triangular relation, so that the inductive effects are approximately balanced.

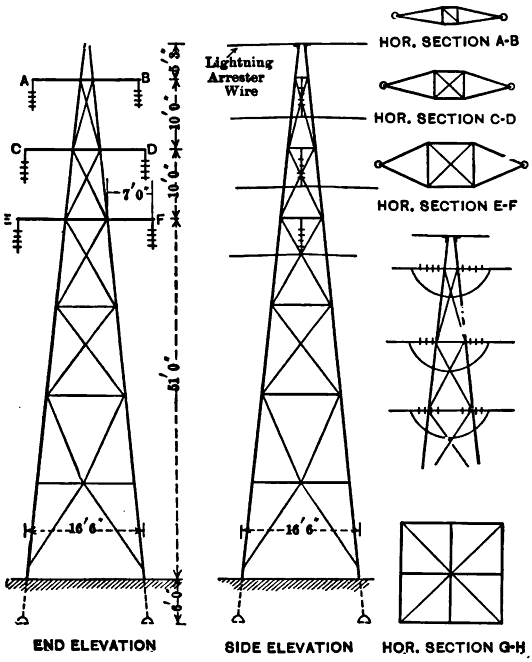



FIG. 62.

The advantages over the ordinary pin-and-insulator construction claimed for this system of supporting wires are:

(a) With the standard type of pin insulator now used, the difficulties of construction increase very rapidly at the higher voltages. The cost of insulator for a given margin of safety increases for voltages above 60,000 nearly as the cube of the increase in voltage. Either very large petticoat diameters must be used or very high insulators with many petticoats. In either case the

manufacture of the porcelain parts is a difficult and expensive matter; and with the long pin necessary, the mechanical stresses from the line on insulator, pin, and cross-arm are objectionable. With the series unit system here proposed, the cost of insulators

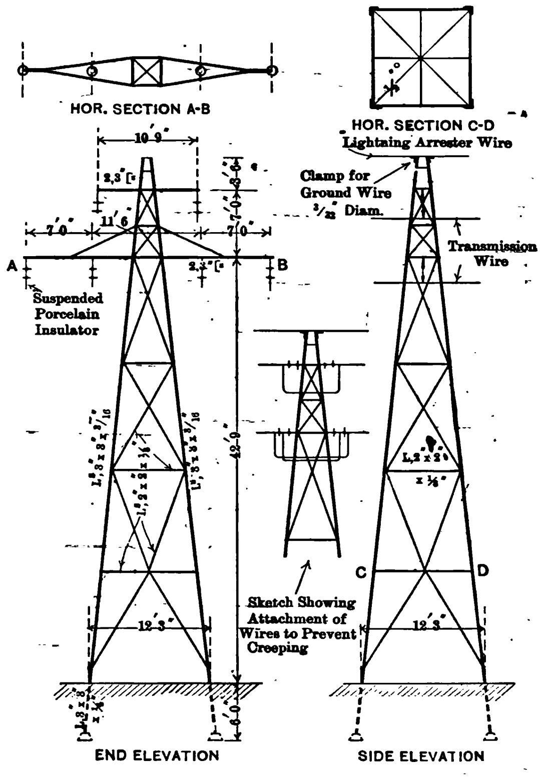



FIG. 63.

progresses only in direct proportion to the increase in voltage, the only change being in the number of units in series. There is practically no limit to the degree of insulation obtainable.

(b) One of the most difficult elements of design in a transmission tower where long pins and petticoat insulators are used is to obtain a cross-arm which will resist the torsional stresses due

to the leverage of the pin. With the pin entirely eliminated, the stresses are directly applied to the cross-arm; this cheapens the construction of the tower.

(c) In the arrangements shown, where the insulating units are attached on either side of the cross-arm, taking the full tension in the line with jumper connections between spans, the insulation can be increased indefinitely by adding discs in series without increasing the space occupied on the tower.

(d) Where each span is dead-ended, as in (c), all faces of the insulating units are exposed to the cleansing action of the rain, so that dirt cannot accumulate thereon. This arrangement also prevents the dripping water from forming electrical communication between units, as occurs from one petticoat to another in the pin type of insulator.

(e) A standard insulating unit can be adopted for all voltages, the only variation being in the number linked in series.

(f) If any insulating unit becomes damaged or completely shattered, the insulation of the remainder is not affected. The damaged unit can be replaced without the necessity of renewing the whole.

(g) If a tower is directly struck by lightning, the cross-arms will be likely to take the discharge, since they are above the lines, whereas in the pin type of insulator the line is usually the highest point.

(h) In long-span installations, where the conductor at each end of the span is tied fast to an insulator mounted on a pin, experience has shown that crystallization is apt to take place in the conductor and the tie, due to its rigidity at that point and the vibrations in the span. This frequently results in breakage of the conductor. The flexible connection between conductor and cross-arm afforded by the series of insulators should reduce this tendency to crystallization, and should therefore permit spans of any length to be used without further precautions against this action.

It might appear that with the conductor suspended under the cross-arm, serious swinging to and fro would take place. From

numerous observations it is believed that no such swinging will occur. Long aërial spans under wind pressure take a permanent and steady deflection throughout the span proportional to the average wind velocity along the span, and no indications have been observed of long spans responding to gusts. The towers are designed so that the conductor can safely be deflected by the wind about sixty degrees on either side of the neutral position.

*Exit from Power-house.* Where the high-tension wires leave the power-house, they must pass through the wall or roof in such a manner as to avoid the possibility of touching any part of the structure, and the ingress of rain is prevented.

Several excellent methods have been devised for the exit of the

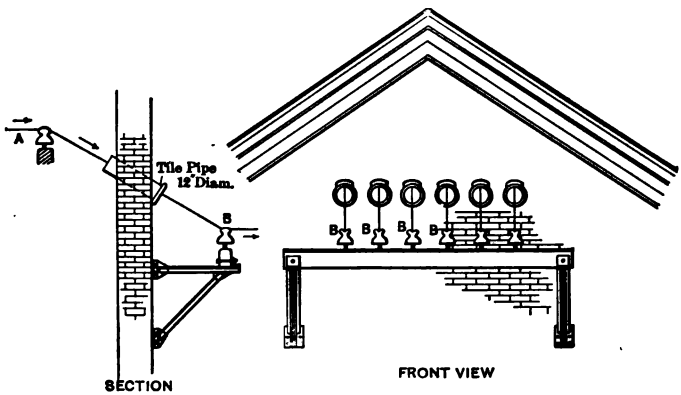



Fig. 64.

line wire. One is shown in Fig. 64 which is suitable for voltages up to 30,000 volts.

Tile pipes 12 inches in diameter, and spaced 14 to 16 inches between centres, are set in the walls sloping downward from inside to outside, as shown. The slope may vary from twenty to thirty degrees to the horizontal.

The wire passes from insulator *A* inside the station, through the tile pipe, to insulator *B* outside the station, the positions of the

insulators being fixed to keep the wire in the centre of the pipe. The downward slope of the wire is to prevent water on the wires from draining into the power station.

Another excellent arrangement is that shown in Fig. 65.

The roof of the power-house is extended out about four feet beyond the wall, and a small box-like room is built below this ex-

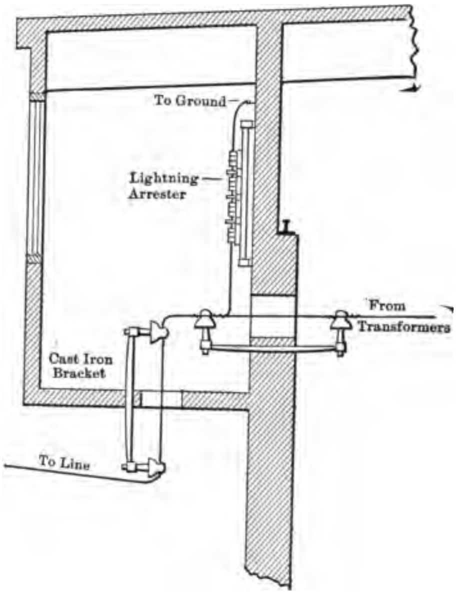



Fig. 65.

tension, as indicated. Holes in the wall—one hole for each wire, the diameter being 12 to 14 inches—allow the wires to pass from the interior of the station into this compartment. The floor or bottom of the compartment has holes in it so that the wires may be turned downward and carried out through them. Two pairs of insulators or brackets serve to support and guide the direction of the wires. The compartment further serves as an enclosure for the lightning arresters, which are installed as shown.

Other methods involving the use of openings covered with glass plates, each plate having a small hole in it for the wire to pass through, have been used. There is, however, always danger of dirt and dust collecting on the plates and providing leakage paths. The general opinion now is that a simple hole of twelve to sixteen inches diameter is the best construction.

## CHAPTER XI.

### LIGHTNING PROTECTION.

UNDER the general classification "lightning arresters" come all that class of devices for protecting a line and the machinery at each end of it from sudden excessive potentials. These may arise from lightning striking the line, or any atmospheric, electrical disturbance that causes a high potential to build up between the line and the earth. Also, static charges, resonance effects, and surging produced by abnormal conditions in the line may produce a high potential the action of which is similar to that of atmospheric disturbances. These potential differences cause discharges tending to equalize themselves, and in every case the charges may be dissipated by a connection of the line to the earth. Unless some path is provided for them, they will go as near to earth as possible by the route of least resistance, *i.e.*, the machinery, and jump through insulation and air to ground, and in their passage will melt wires and destroy the insulation.

Also, lightning splinters poles and cross-arms and breaks insulators.

To prevent the line potential from rising to an excessive value above that of the earth, barbed wire strung on insulators on the same pole line, above the transmission wires, has been used. The barbed wire is well connected to earth about every quarter of a mile. The barbs offer multitudinous points for the discharge of static electricity, and they are always at the potential of the earth because of the numerous ground connections. Therefore, the region surrounding the wires of the line are kept continually at the same potential as the earth.

This arrangement, while helpful, does not alone meet the neces-

sities of the case, and in addition to it other forms of lightning arresters must be installed.

The standard lighting arrester now in use is made up of a number of small knurled metallic cylinders, set side by side in a porcelain frame and separated from each other by small air gaps. A cylinder at one end of the group is connected to the line; the cylinder at the other end is connected to the ground. The air gaps prevent the normal line potential from sending current to the earth by this path, but excessive potentials will jump the gaps from cylinder to cylinder until the ground wire is reached.

In order to make these arresters effective, there must be some device to oppose the rush of discharges to the station and compel them to take the path to the ground through the lightning arresters. Choke coils, or flat coils of copper wire or ribbon which have a copper area sufficient to carry the line current easily, present a barrier to the passage of lightning or other high-frequency discharges. The inductance of the coils creates but little opposing voltage to the line current, of 25 to 60 cycles per second frequency,

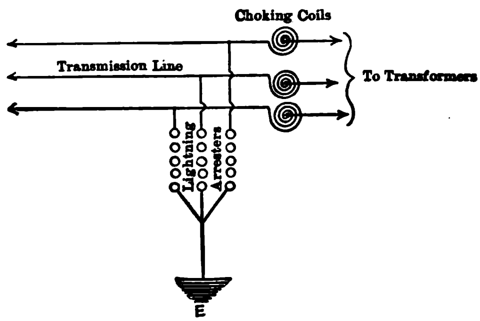



FIG. 66.

but in the case of oscillatory discharges, where the frequency may run up into the millions, the opposition to the passage of such discharges is so great that the path through the arrester air gaps is the easier.

Fig. 66 shows the connections for lightning arresters and choke

coils, between the transformers or generator and the line. The arresters are each connected on one side to a line wire, and on the other side to the earth.

Lightning arresters are almost valueless without choke coils.

A form of combined lightning arrester and choke coil is de-

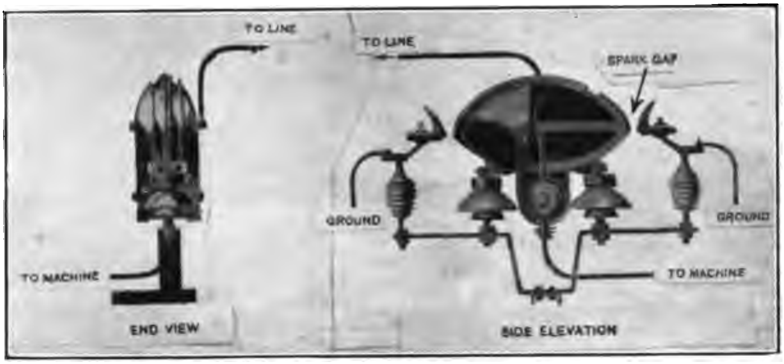



FIG. 67.

picted in Fig. 67. This has been successfully used in Europe, and possesses certain advantages.

It comprises several cast-iron shapes, shells, and diaphragms which when assembled together form an egg-shaped structure as shown. These several cast-iron parts are connected together by copper wires, the various sections being in series. From the last section on one side a connection is made to the choke coil, and from the other terminal of the choke coil the wire passes to the dynamo. The line wire is attached to the first of the cast-iron sections. Near the ends of the structure are placed horn-shaped pieces of metal, the distance of separation between the end and the horn-shaped piece being adjusted to form a discharge air gap, the latter pieces being connected to the ground as shown. The current from the dynamo passes through the choke coil, thence to the cast-iron piece connected to it, then, by means of the short connecting wire, to the next cast-iron piece, and so on until it reaches the line. The electrical resistance of the device is so small as to be negligible, and

the inductance of the choke coil is low, so that but little opposition is offered to passage of the normal station count. When, however, a sudden charge, seeking earth, comes in over the line, it spreads over the large surface presented by the shell and tends to charge it electrostatically, which condition causes a concentration of potential at the pointed ends of the shell also. The rapid passage from cast iron to copper, again to cast iron, and to copper, and so on through the several sections of the shell, combined with the action of the choke coil, sets up a strong retarding action to the passage of high-frequency currents, which compels the charge to pass across the air gaps to the horn-shaped pieces and thence to earth.

Another good form of lightning arrester is known as the horn

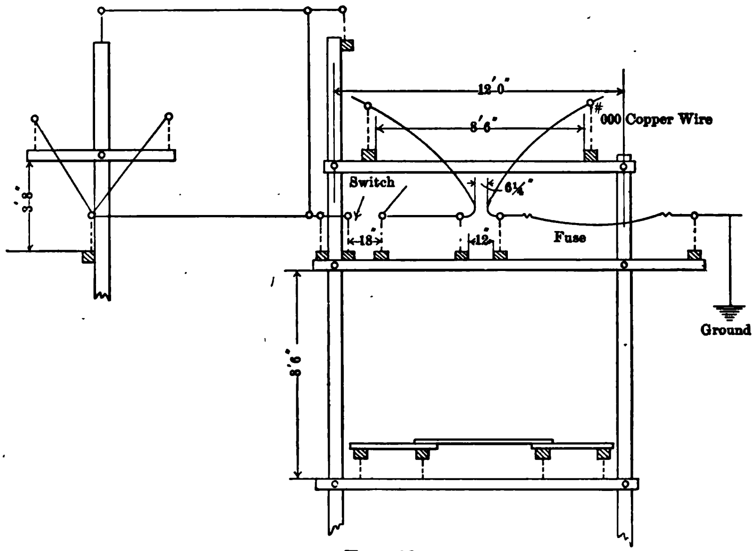



FIG. 68.

type. This is made of ordinary copper wire size No. 000, bent in the form shown in Fig. 68. Two of these bent pieces supported on insulators form an arrester; one horn is connected to a line wire, while the other is connected to the ground through a fuse.

The dimensions given in the figure are those for a 50,000-volt

system. For smaller potentials the air gap between the horns is correspondingly diminished.

A simple and effective form of arrester used in Europe comprises a plate of copper attached to each of the line wires against which a small stream of water is thrown from a nozzle. The re-

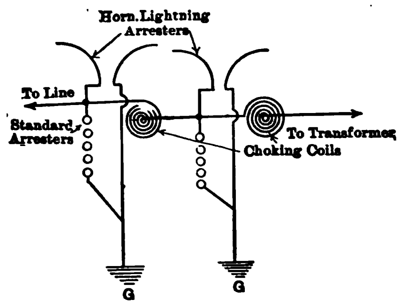



FIG. 69.

sistance of the water is too high to allow any appreciable leakage of current, but forms a good path for lightning or static discharges.

To thoroughly protect a line there should be installed two choke coils in series with each wire, and two different forms of lightning arresters attached to the line next to the outer choke coil, and two more arresters of different types installed between the choke coils; and this arrangement should be duplicated at both ends of the line. Fig. 69 indicates this method of protection, using standard cylinder arresters and horn arresters, a single wire only of the circuit being shown.

In long lines standard or horn arresters should be placed every two or three miles along the line, the distance apart depending on the frequency and violence of thunder-storms and other atmospheric electrical disturbances.

In regions where such phenomena are frequent, it is advisable to use the overhead barbed wire, before described, in addition to the lightning arresters along the line.

Unless the ground connections are all well made to some point which is continuously damp, they will not form the required low-

resistance path to earth. If it is necessary to locate them where the ground is always dry, a small water pipe should lead to the earth at the ground connection and enough water allowed to constantly drip to keep the place damp. The ground connection to the arrester may be made by connecting to water pipes where they are two inches in diameter or greater; in other cases copper plates not less than two feet square and one-sixteenth inch in thickness should be sunk in the ground to a depth of five feet or more, depending on the depth at which permanent dampness is reached.

Coke, broken into fine particles, is packed on either side of the plate, the thickness of the coke being at least six inches; the ground wire is securely soldered or brazed to the plate and carried straight upward to the ground terminal of the arrester. The ground wire should be No. 00 solid copper. If possible there should be no bends in it whatever; and if there are more than two ninety-degree bends in it, its efficiency will be impaired.

## CHAPTER XII.

### Switching and Controlling Apparatus.

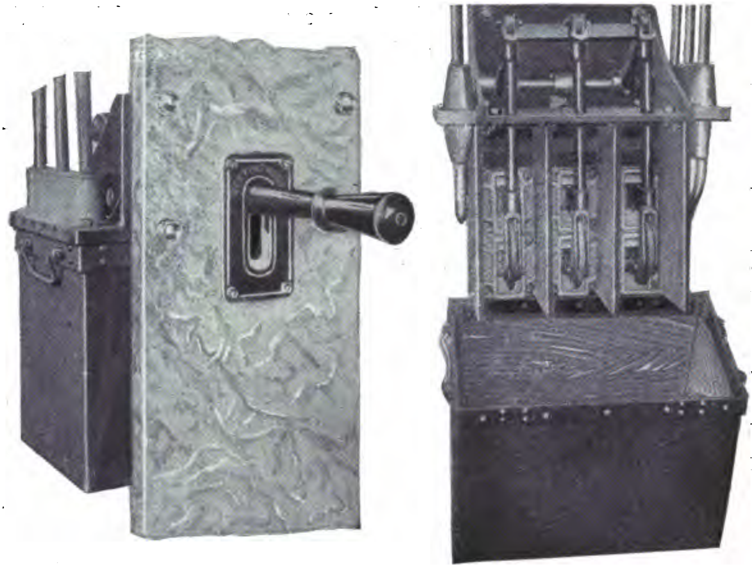
All switches for potentials above 2,000 volts should be of the kind that have their blades and clips submerged in oil and known as oil switches. The switches themselves are placed back of the switchboard, and manipulated from the front by means of handles that pass through the board to the front, and which connect by rods or links with the switching mechanism. In some cases the switches are placed on the wall in the rear of the switchboard, the handles being on the front, and connecting by links or rods to the switches. A standard switch of this type is shown in Fig. 70.

This arrangement is suitable for pressures up to 10,000 volts. Above this, the switches should be placed in brick or concrete chambers beneath the switchboard and worked by handles on the board mechanically connected to the switch gear. In the case of large switches for high potentials, the switch, instead of being moved directly by hand, is operated by a motor or a large magnet which is controlled by a small, low-potential hand switch. Current from the exciter dynamo is generally used to work the motor or magnet moving the switch.

These switches may be made to open automatically with excessive current flow, by means of a controlling magnet to actuate the switch that sets in motion the operating magnet or motor, the magnet being set to move when the line current exceeds a certain predetermined value. When so arranged, they serve the double purpose of automatic circuit breakers and hand switches.

When the potential exceeds 10,000 volts and the amount of energy transmitted over each switch is 350 K.W. or more, it is advisable to place each pair of contacts in a separate fireproof

chamber; that is to say, a three-phase switch becomes, in effect, three single-phase switches, all actuated simultaneously by a single mechanism common to the three. The high-tension bus-bars are also enclosed in a long horizontal fireproof compartment which runs along just above the switch compartments. The sides of this bus-bar chamber may be made of brick, tile, or concrete. Fig. 71 shows a high-tension switch for 60,000 volts with its three contacting



Front. Rear. (Oil Chamber Lowered.)

FIG. 70.

parts in three separate brick chambers. This switch is operated electrically by heavy magnets which may be partly seen, their plungers connecting to the operating-chain links attached to the main lever arm.

Ordinary knife switches are satisfactory up to 600 volts; and where the energy transmitted over each switch does not exceed 500 K.W., these may be used as main dynamo switches with low-tension generators, the voltage being raised by step-up transformers.

These also are used for the exciter dynamos and the generator fields.

The exciter current is usually of low voltage, either 125 or 250 volts, and the exciter switchboard is built on the same lines and

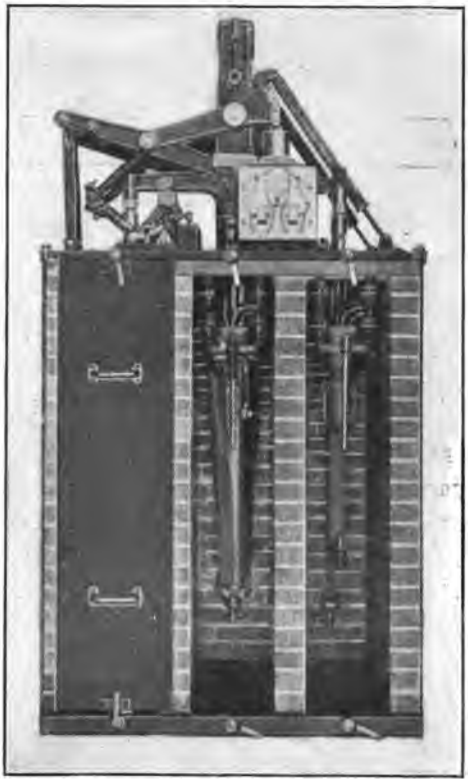


FIG. 71.

principles, as those which guide the design of any direct-current switchboard, the instruments being mounted on marble panels from $1\frac{1}{2}$ to 2 inches thick, which are in turn supported on vertical sections of angle iron, to which the slabs are bolted. Felt or rubber washers about one-eighth inch thick should be interposed between the

iron and the marble. Adjacent panels are joined together by bolting the adjoining webs of two separate supporting angle bars together by $\frac{3}{8}$-inch bolts, spaced 18 to 22 inches apart along the length of the angle sections. Fig. 72 is a plan view showing a portion of two adjoining marble slabs each bolted to its supporting channel bars, the latter being bolted together. An angle section

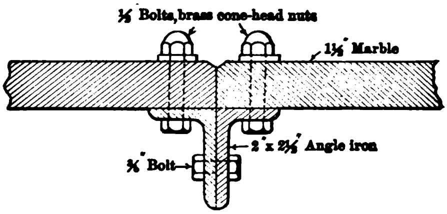



FIG. 72.

$2 \times 2\frac{1}{2}$ inches is a good size to use, the narrow web being bolted to the marble.

It is customary to install a separate panel for each dynamo. The exciter panels are usually placed at one end of the board, and the generator panels at the other end. A totalizing panel is generally put in the middle of the exciter panels on which are mounted instruments to show the total output of all the exciters working together, while a totalizing panel for the purpose of registering the total output of the generators is put in the middle of the generator panels.

There have been a number of methods suggested for switchboard and switching connections, some of which are highly complicated; and the multiplicity of connections and the numerous switches are more liable to prove sources of trouble than to be of much assistance. Furthermore, high-tension switches are expensive and, unless carefully worked out, the switchboard may be a source of great and unnecessary expense. Fig. 73 shows an arrangement which the author considers amply complete and flexible. $G_1$, $G_2$, and $G_3$ are three-phase generators excited by fields $F_1$, $F_2$, $F_3$. The generators connect through the generator switches

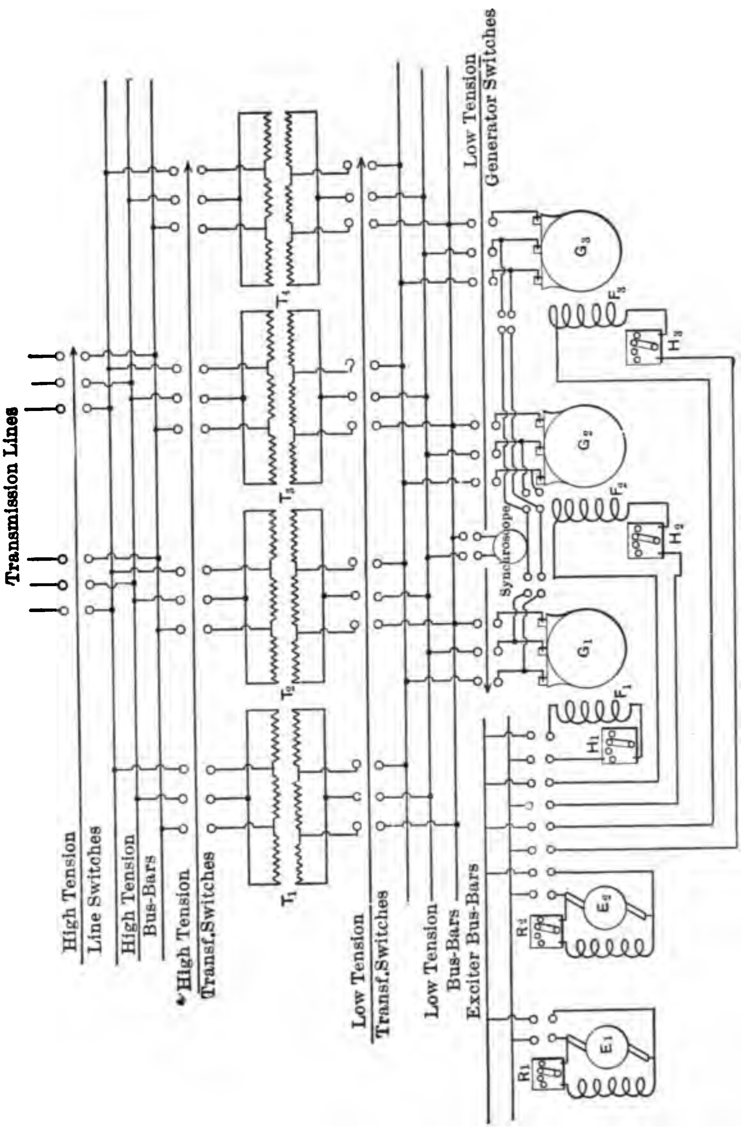

Transmission Lines
High Tension
Line Switches
High Tension
Bus-Bars
High Tension
Transf.Switches
Low Tension
Transf.Switches
Low Tension
Bus-Bars
Exciter Bus-Bars
Low Tension
Generator Switches
Synchroscope
T1
T2
T3
T4
G1
G2
G3
F1
F2
F3
H1
H2
H3
E1
E2
R1
R2

FIG. 73.

to a set of three-phase, low-tension bus-bars. $T_1$, $T_2$, $T_3$, $T_4$ are step-up transformers connected in mesh as shown, and any transformer may be joined to the low-tension bus-bars by means of the low-tension transformer switches which connect to the transformer primaries. These generator and transformer switches may be ordinary knife switches if the voltage of the generators does not exceed 600 volts and the K.W. capacity is not above 500. It is well, however, to use automatic circuit breakers, which may be tripped by hand, for the generator switches, and these will disconnect in case of overload or can be operated manually when desired.

A set of high-tension bus-bars has a series of high-tension switches connecting them to the step-up transformer secondaries, and the outgoing transmission lines are joined to the high-tension bus-bars by high-tension switches similar to those connecting the transformer secondaries to the high-tension bus-bars. The transmission line switches should be provided with automatic tripping coils which will cause them to open if the current should exceed a predetermined amount.

$E_1$ and $E_2$ are exciter dynamos which connect by means of ordinary knife switches to the exciter bus-bars. The generator fields also connect to the exciter bus-bars each through its own field switch as shown, the current passing through the generator field rheostats $H_1$, $H_2$ and $H_3$. By means of rheostats $R_1$ and $R_2$ the voltage of the exciters may be adjusted. These machines may be run in parallel or either one, singly, can be used to supply current to the exciter bus-bars. The field of any generator may be switched onto or off from the bus-bars, and each generator field may be individually adjusted by means of the rheostat in its circuit. Any of the main generators may be switched on or off the low-tension bus-bars, any transformer may be cut out of service, and either of the transmission lines or both may be disconnected.

This diagram does not indicate any instrument connections except that of the synchroscope. As shown, this is connected to the generator bus-bars by means of a small switch on one side.

Its other side connects to several small switches—three in this case. By plugging in the switch to the bus-bars and any one of the switches connected to the generator terminals, the relative frequencies of the bus-bar and the generator to which the instrument is connected are indicated. This device is for the purpose of showing whether the frequency of a generator, which is not connected to the bus-bars, is greater or less than that of the bus-bars, so that the speed of the disconnected generator may be raised or lowered until the frequencies are the same; and when this condition is reached, the pointer comes to rest in its middle position and thereby indicates that the synchronized generator is ready to be connected to the bus-bars, it being assumed that the voltage has been previously adjusted to its proper value.

Voltmeters should be installed so that the following indications may be taken:

1. Voltage of *each* generator.
2. Voltage of low-tension bus-bars.
3. Voltage of high-tension bus-bars.

Up to 600 volts voltmeters are connected directly to the circuit to be measured. Above that, however, a transformer is connected

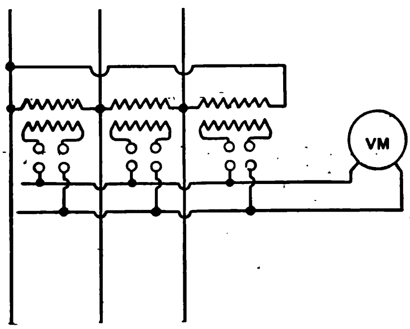



FIG. 74.

to the circuit, and the voltmeter is connected to the secondary side of the transformer. Fig. 74 shows a three-phase line with the primaries of three small transformers connected across the three

phases. The secondaries leave the three small switches which latter connect to a pair of wires leading to the voltmeter. By throwing in any switch a single voltmeter is made to indicate the voltage of each of the three phases. Where three-phase systems are balanced—that is, equal current passing over each of the three wires—it is necessary only to take the voltage of one of the phases, as the voltages of all the phases will all be equal. This is the condition existing in nearly all transmission systems; and in them only one transformer with its secondary connected to the voltmeter is required.

Ammeters on high-tension circuits are also connected to trans-

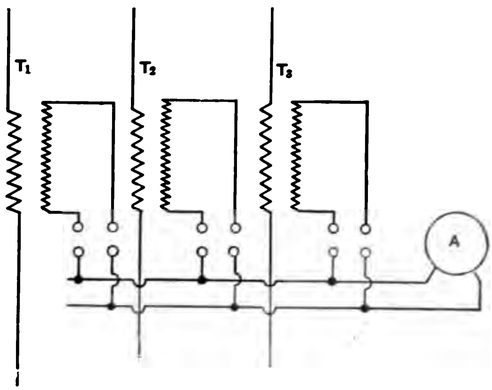



FIG. 75.

formers in which the primary consists of one or two turns in series with the main current. The secondary consists of a number of turns, its terminals being connected to the ammeter. Obviously, the volts generated in the secondary will be proportional to the current in the main line passing through the primary. The instrument itself is in reality a voltmeter; but the movements of its needle being proportional to the current passing in the main line, the markings of its dial are in amperes. Fig. 75 shows the connections.

Wattmeters record the quantity of electrical energy generated;

and the usual type of integrating instrument makes a continuous record of total energy delivered over a certain period of time. These have two windings, one a shunt, the other a series winding; and therefore, potential and series transformers both are required for them.

Circuit breakers which work on high-tension lines must take current for the tripping coils from series transformers. It is customary, where ammeters, voltmeters, and wattmeters are to register on the same circuit, to put in one potential and one series transformer, each large enough to provide current for its instrument and the wattmeter also; and if a circuit breaker operate on the line, the series transformer is large enough to supply current to its tripping coil, in addition.

Synchroscopes on high-tension circuits are connected to the secondaries of potential transformers instead of directly to the line as shown in Fig. 73.

Other alternating-current instruments are, power factor meters and frequency meters. The former are not necessary except under certain special conditions, the second only a convenience and in no wise essential.

Ground detectors are necessary in every plant. These indicate the existence of a contact between the earth and any one of the lines. The type of detector now used is electrostatic, in which no current passes through it. The connection is made either direct to the instrument or to the terminals of a condenser, the connections in the former case being as indicated in Fig. 76. When connected directly to earth a fuse or graphite resistance must always be placed in the ground connection so that in case of the vanes becoming bent so that they approach each other and an arc should leap across, the current flow would melt the fuse and protect the device.

A better way of installing these instruments is to use small condensers which are supplied for the purpose. No matter whether the vanes are in contact or not, the current flow is so limited that neither the condensers nor the instrument can be injured.

The relative value of circuit breakers and fuses is a subject still under discussion, and each case must be separately considered. Fuses, when properly made, can be used successfully under potentials up to 6,000 volts where the power does not exceed 100 K.W. Such fuses are from 12 to 18 inches in length and are surrounded by porcelain tubes, with sand packed in the tube around the fuse.

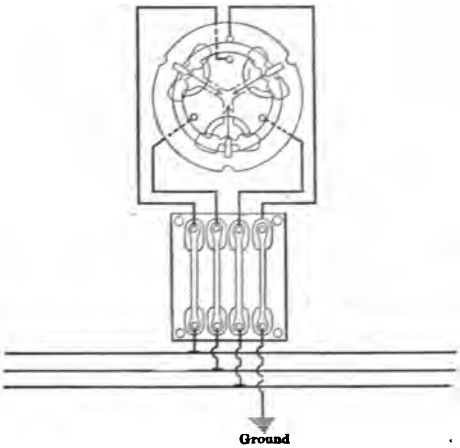



FIG. 76.

With lower potentials, as much as 200 K.W. may be interrupted by fuses. In plants having units larger than this, automatic circuit breakers should be used and made to serve at the same time as switches.

In a properly designed switchboard there will be no parts on it carrying high potentials. The high-pressure switches and busbars will be in their fireproof compartment, with operating handles only on the face of the board—usually coming through the marble from the rear—or simply small, low-potential knife switches to actuate the operating magnets or motors which move the high-potential switches. All instrument transformers are mounted either on the wall in the rear of the switchboard or on the horizontal iron braces running from the switchboard to the wall, only the low-

tension wires from their secondaries going to the instruments on the board.

The direct-current panels for the exciter have no special instruments on them other than standard voltmeters, amperemeters, and knife switches, with the single exception of the field switches to the main generator fields. These are ordinary knife switches each having a pair of auxiliary contact clips which the switch blades do not touch when the switch is closed. In opening it, however, the blades touch these clips just before leaving the clips connected to the exciter bus-bars. The auxiliary clips are joined together by a resistance. At the instant when the switch blades are on the point of leaving the bus-bar clips and are making contact with the auxiliary clips, the resistance is connected in parallel with the generator field. A further movement of the switch handle disconnects the blades from the bus-bar clips, but leaves them still in contact with the auxiliary clips, and the resistance between these latter provides a path for the inductive discharge of the generator fields. Without such an arrangement, instantaneous potentials are set up on opening the field circuit which may be great enough to cause break-down of the insulation.

In designing the board, allow not less than two inches between bare metallic parts of opposite potential for 125-volt boards and 2½ inches for 250-volt boards. Keep at least 2 inches away from the angle-iron supports for the slabs. Current densities per square inch should be 1,000 amperes in bus-bars, 750 to 800 amperes in the switch blades and clips, 100 to 125 amperes between surfaces bolted together, and 50 to 55 amperes between switch blades and clips.

# APPENDIX

## COMPUTATION OF PRESSURES SET UP IN LONG PIPES WITH CHANGE IN GATE OPENING

*Abstract from a paper presented April 9, 1906, before the American Institute of Electrical Engineers on*

## A NEW METHOD OF TURBINE CONTROL.

BY LAMAR LYNDON.

IN the case of a turbine fed by a long, closed pipe, it is evident that any change in the gate opening must be accompanied by a change in the velocity of the column of water, and since this column has weight, velocity, and is practically incompressible, kinetic energy, proportional to its mass and the square of the velocity, is stored in the moving water, and any change in its velocity must be accompanied by a corresponding change in its energy, which can only take place by change in the internal pressure in the pipe.

Starting with the formula, the basis of mechanics,

$F = M\ A$, in which

$F$ = force or pressure in pounds;

$M$ = mass = weight in pounds $\div$ 32.2;

$A$ = acceleration in feet per second;

the change in pressures for changes in gate opening can be deduced.

Let $S$ = area of pipe in square feet.

$L$ = length of pipe in feet.

$W$ = weight of a cubic foot of water = 62.5 lb.

Then $S\ L\ W$ = total weight of water in the pipe at any time, and its mass $= \dfrac{S\ L\ W}{32.2}$. (1)

If $C_1$ = velocity in feet per second with a given gate opening;
$C_2$ = velocity with a reduced gate opening;
$T$ = time of change in seconds,
then $P$, the pressure set up will be,

$$P = \frac{SLW}{32.2} \times \frac{C_1 - C_2}{T} \qquad (2)$$

which is the total pressure to retard the mass of water.

If $p$ = pressure in pounds per square inch,

$$p = \frac{P}{S \times 144} = \frac{SLW}{S \times 144} \times \frac{C_1 - C_2}{32.2\,T} = \frac{L(C_1 - C_2)}{74.3\,T} \qquad (3)$$

this being the formula for excess pressure above that due to the head when the gate opening is reduced, or the reduction in pressure to be subtracted from the head at the time when the gate opening is increased. It is to be noted that the pressures per square inch are independent of the diameters of the pipes.

As an example, take a pipe 1,000 ft. long; head at the turbine 90 ft.; velocity of water in the pipe 6 ft. per second at full gate. Reduce this opening to 70 per cent. gate in three-fourths of a second. The reduced velocity of the water is 70 per cent. of 6 = 4.2 ft. per second.

$$p = \frac{1{,}000\ (6 - 4.2.)}{74.3 \times 0.75} = 32.3 \text{ lb.}$$

The head on the turbine is 90 × 0.434 = 39 lbs. normal. Percentage change in the pressure is $\dfrac{32.3}{39} = 83$ per cent.

If the gate were moved from 70 per cent. to 100 per cent. opening as above, the net head acting for the short time of gate movement would be 39 − 32.3 = 6.7 lb., or about 17 per cent. of the normal head.

When the gate is completely closed, the phenomena are very different, as are the laws which govern them. These will now be investigated.

If the gate were closed instantaneously, the excess pressure set up would be infinite if it were not for the ductility of the conducting pipes and the elasticity of the water itself. Because of these effects, however, the pressures produced by instantaneous closing of the gate are not infinite, but, from a theoretical viewpoint, small, though exceedingly great when considered as hydraulic effects, to be taken care of in practice.

For increase of pressure when the valve is closed instantaneously the formula is

$$p=c\left(\sqrt{\frac{\omega E E' t}{g(t E'+2 R E)}}\right) \qquad (4)^*$$

in which

$p$ = increase in pressure per square inch;

$c$ = initial velocity in feet per second;

$\omega$ = weight of a prism of water 1 ft. long and 1 sq. in. in cross-section = 0.43416;

$E$ = modulus of compressibility of water = 294,000 lbs. per sq. in. = $294 \times 10^3$;

$E'$ = modulus of elasticity of plate iron = 30,000,000 lbs. per sq. in. = $3 \times 10^7$;

$t$ = thickness of pipe plate in inches;

$g$ = acceleration due to gravity = 32.2;

$R$ = internal radius of pipe in inches.

Take, for example, a pipe of 5 ft. diameter, the thickness of the pipe wall being 0.25 in., and the velocity of the water in the pipe being 6 ft. per second. Substituting the above values of $\omega$, $t$, and $R$,

$$p=6\left(\sqrt{\frac{0.434\times 294\times 10^3\times 3\times 10^7\times 0.25}{32.2(0.25\times 3\times 10^7+2\times 30\times 294\times 10^3)}}\right)$$

whence $p=6 \times \sqrt{1,182}=206$ lbs. per sq. in.,—a pressure which approaches the rupturing point of the pipe.

As may be seen, the pressure produced by *instantaneous* closure is independent of the length of the pipe. An appreciable

*Church's "Hydraulic Motors," p. 208.

time, however, is required to close any valve, and with the introduction of the time element the length of the pipe also enters as a factor into the problem. The theory, in general, of the phenomena which take place on instantaneous gate closure is that the kinetic energy of the moving mass of water changes to potential energy, distending the pipe and compressing the water. This compression of the water continues for only an instant, as immediately after compression it begins to extend itself; this act of extension again sets up the pressure and causes compression. The cycle is repeated, and this continues until the friction of the water in the pipe and the molecules against each other decrease the amplitude to nearly zero. The whole occurrence is an oscillatory one and resembles somewhat the phenomenon of "surging" in electrical transmission lines carrying alternating currents. The velocity of the "wave propagation" is the same as the velocity of sound in water, and this velocity varies with varying conditions of thickness of pipe shell, modulus of material of shell, and its internal radius. The formula for the velocity of wave propagation is,

$$v=\sqrt{\frac{g}{\omega}\times\frac{EE't}{tE'+2RE}} \qquad (5)^*$$

Formula (4) may also be written

$$p=\frac{cvW}{g} \qquad (6)$$

in which $v$ = velocity of wave propagation in feet per second;

$W$ = weight of a cubic foot of water.

$$v=\frac{pg}{cW}$$

If $p=206$ as given in the foregoing problem,

$$v=\frac{206\times 144^{\dagger}\times 32.2}{6\times 62.5}=2{,}540 \text{ ft. per sec.}$$

* Church's "Hydraulic Motors," p. 208.

† Constant 144 is to reduce the cross-section of a cubic foot of water to square inches.

Assume the pipe 1,000 ft. in length. Then the time required for the wave to travel from the gate back to the end of the pipe and return to the gate is $\frac{2 \times 1,000}{2,540} = 0.788$ second. This may be termed the "time constant" of the pipe for the velocity of water flow of 6 ft. per sec., and designated by $T_0$. If the gate be closed within the time of one complete wave cycle, *i.e.*, 0.788 second for this case, ***the pressure set up is the same as if the gate had been closed instantaneously.***

If the pipe were 3,000 ft. long, the time constant would obviously be three times the above or 2.364, say $2\frac{1}{3}$ seconds, and, in order to avoid the heavy pressure computed, the gate must not close within this time of $2\frac{1}{3}$ seconds.

If a longer time be taken to close the gates, the pressure set up will be directly proportional to pressure due to instantaneous closing in the inverse ratio of $T_0$ to $T_x$, where $T_x$ is the time in which the gate is closed; that is, $p : p'' :: T_0 : T_x$. Thus if 4.5 seconds are taken to close the gate, for conditions as above and a length of pipe of 1,000 ft., the pressure produced will be $206 \times \frac{0.788}{4.5} = 36$ lbs. For a 3,000-ft. length of pipe the pressure will be $206 \times \frac{2.264}{4.50} = 108$ lbs.

These formulas and facts have all been experimentally proved by Joukovsky in a series of experiments conducted at Moscow, Russia, in 1897–1898, in pipes up to 24 in. in diameter. They show conclusively the necessity for compensating for the change in energy in the water column at the time of governing, if the gates are to be moved quickly for rapidly fluctuating loads.

# PART III

## DESCRIPTIONS OF HYDRO-ELECTRIC GENERATING AND TRANSMISSION PLANTS.

### THE TOFWEHULT–WESTERWIK TRANSMISSION SYSTEM, SWEDEN.

*Abstract from "Electrical World" Sept.* 28, 1907.

AN electrical equipment recently installed in Sweden for transmitting energy from Tofwehult to Westerwik possesses some interesting details, which are outlined below. The plant consists of a power-house at Tofwehult, a transmission line thence to the town of Westerwik, and transformer and converter stations in that town.

### THE POWER-HOUSE.

The natural surroundings of the waterfall at Tofwehult rendered it especially favorable for development, because it is situated between two lakes, and the connection between these, which forms the fall, consists of a deep cleft with almost vertical sides. In consequence the hydraulic work was very simple and cheap; the costs of the hydraulic work and the power-house building amounted to only \$26,000, which, on the basis of the maximum output of 1,300 horse-power, including the reserve, is only \$20 per horse-power. The power-house is built for three generating sets, two for 325 H. P. each, and one for 650 H. P. Only the two smaller sets are now installed.

The turbines showed under test an efficiency at full load of 81 per cent., and a speed variation of only 6 per cent. at a load variation from full load to no load. An interior view of the power-house is shown in Fig. 77. Each of the generators is built

for 10,000 volts and 285 K.V.A. The major insulation of the armature coils consists of several layers of oiled cloth and a final coating of an insulating compound. At the insulation test of one of these coils, the break-down occurred at 45,000 volts.

A separate extension of the power-house is provided for the

FIG. 77.—INTERIOR OF POWER-HOUSE.

switch gear, as seen in the illustration Fig. 78. The lightning arresters are placed on the upper floor of this extension. The lower floor, which is separated from the generator hall by the switchboard, contains all other apparatus and instruments for low and high tension. The high-tension equipment is placed in a compartment separated by iron gratings and accessible from both sides.

In order to prevent the accumulation of static electricity on the high-tension line a static protector is provided. This apparatus consists of six vertical glass pipes, two for each phase, (Fig. 78), through which water flows continuously. The upper connection between the two pipes of each phase consists of an iron faucet which is connected to the corresponding bus-bar. The iron pipes, through which the water is carried to and from the apparatus and which are connected to the lower ends of the glass

pipes, are grounded. The water being very pure and therefore its specific resistance being high, the current leaking through the apparatus is small, amounting to only 0.036 amp. per lead;

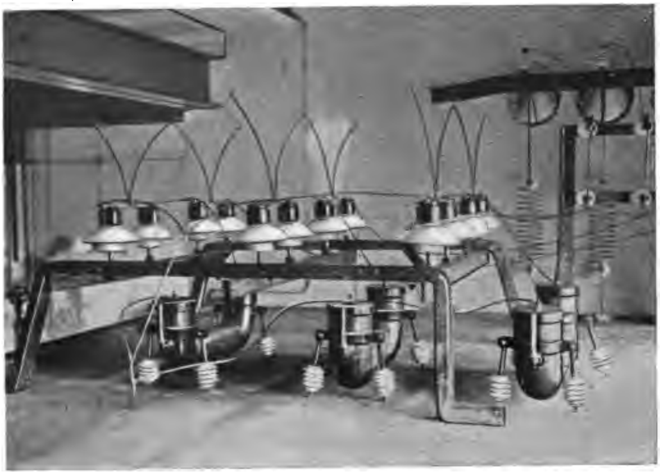


FIG. 78.—LIGHTNING ARRESTERS

this value is probably rather too small to secure a good efficiency of the device.

## THE HIGH-TENSION LINE.

About half way between Tofwehult and Westerwik a deep bay of the Baltic cuts into the land. If the transmission line had been erected around this bay the length would have been increased by 3.75 miles above the straight distance of about 9 miles between the power-house and the town. The increase could be avoided by crossing the bay by means of either a submarine cable or a long overhead span. In order to obtain sufficient security against break-downs of a cable in the middle of an overhead line of 10,000 volts it would have been necessary to install special protection devices and to lay two cables. Even if these provisions had been made, the crossing by cable would not

only entail a lower degree of working security, but would also cause higher running costs. Since, not far from the straight line between the power-house and the town, the bay forms a narrow strait with steep shores, it was decided to build at this point an overhead span of sufficient height to avoid all sails. The length of the span is 735 ft., and the height over the water is, at the lowest point, 131 ft. The conductors consist of steel wire ropes, each 60 sq. mm. in cross-section; they are supported by iron masts, each having a height of 82 ft., two on each side, which carry insulating supports.

A view of an insulating support is given in Fig. 79. It consists of an oak block, resting on six high-tension insulators. The

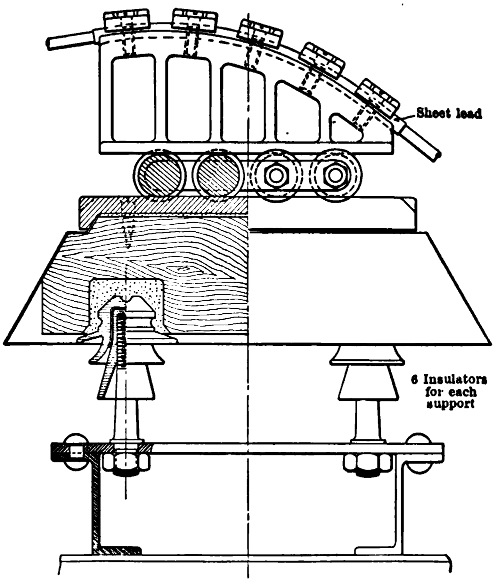



Fig. 79.—Saddle Support For Long Wire Span.

insulators are cemented to the oak block, their iron pins being fastened to the brackets of the mast. The oak block is protected against moisture by a coating of sheet zinc. In order to prevent the pull of the wire ropes from acting on the masts, a rolling de-

vice is provided. The rolling device consists of a cast-iron plate resting on the oak block, four cast-iron rolls, and a cast-iron piece which rests on these rolls and to which the wire ropes are fastened by screws. The terminals of the wire ropes are anchored to the rock. Thus they act as a guy to the casting to which the wire rope is fastened, and prevent it from rolling out of the cast-iron plate. Slipping to the side is prevented by flanges on the rolls. Four wire ropes are mounted in this way, one of which serves as reserve. As stated the cross-section of each rope is 60 sq. mm. Each wire rope has, therefore, the same conductivity as a copper wire about 7 sq. mm. in cross-section. At 30° C. the strain in the span part of the rope is 1,300 lbs., and in the guy part 1,650 lbs. Thus the maximum stress equals 17,800 lbs. per sq. in., corresponding to a safety factor of 5.. The sag of the rope at 30° C. equals 29.5 ft. In spite of this sag a contact between the ropes

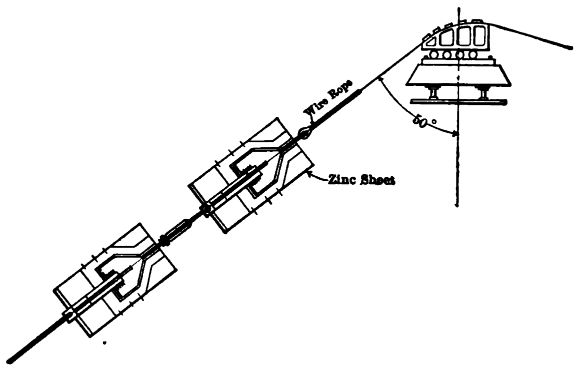



FIG. 80.—METHOD OF ANCHORING WIRE CABLE SPAN.

is impossible, since they are mounted at different heights, and the horizontal distance of about 6.5 ft. is ample. Moreover, it has been proved that even in a strong wind the wires do not swing; all of the ropes are deviated to the same constant angle from the vertical plane whereby the distance between the ropes is not changed.

As the wire ropes are anchored to the rock it is necessary to

put special-strain insulators into the guy part of the ropes. The strain insulator which is shown in Fig. 80 must withstand a mechanical force of 1,650 pounds and at the same time secure a good insulation. The insulators are coupled in series by twos; therefore, at the regular working conditions each insulator is subjected to a voltage of 3,000. Still, in order to get a high degree of security, each insulator was designed for 20,000 volts. The insulator is covered on the top and sides by a cap of sheet zinc whereby it is perfectly protected against moisture. The dry insulator in actual tests withstood a tension of 25,000 volts. As to the mechanical strength a lining of sheet lead between the iron and the porcelain effects an equal distribution of the mechanical pressure upon the latter; and since porcelain possesses a great strength against pressure it was not difficult to make the span insulators sufficiently strong mechanically.

A telephone circuit is erected on the high-tension line poles. For this line common telephone insulators are used; the telephone lines are transposed at every fifth pole. The high-tension line is transposed one turn at every 1,000 ft. In telephoning over this line a humming sound is heard. The noise is not so loud as to disturb the conversation. It is probably partially caused by the grounding of the neutral point at both the transformer station and (through the static protectors) in the power-house.

## Transformer and Converter Stations and Distributing Cable.

In the main transformer station at Westerwik the current is transformed to 500 volts three-phase and 3,000 volts, three-phase. The former voltage is used for distribution within an industrial district in the neighborhood of the transformer station; the latter is used for transmission to the converter station which is built close to the old city plant. The converter station is arranged for four motor-generator sets; two of those are installed at present. The direct E.M.F. is $2 \times 110$ volts, but every-

thing is so planned that later on an E.M.F. of 2 × 220 volts can be adopted without any difficulty. The station reserve equipment includes a storage battery, while the steam-driven direct-current generators of the old city plant also constitute a valuable reserve. Transformer station No. 2 supplies energy to some factories in its neighborhood by means of three-phase current at 500 volts.

The distribution of the direct current used in private lighting, for small motors, and for the street lamps within the city is accomplished by means of underground cables. The street lighting is furnished by 65 enclosed, 7-ampere arc lamps. The lamps are connected two in series across the 220-volt supply mains.

The costs given below refer to the two generator sets installed at the present time. The total cost of the fully installed power-house and equipment for 1,300 H.P. would be about $46,000. Referred to the entire equipment including the reserve, namely 880 K.W., the cost was $52.70 per K.W. at the power-house and $65.40 at the end of the high-tension line; the corresponding costs per horse-power are $39 and $48, respectively.

The following list costs of various items may prove of interest:

COST OF EQUIPMENT.

| | |
|---|---|
| Dam and power-house | $26,200.00 |
| Two 325-H.P. turbines and two 43-H.P. turbines | 4,800.00 |
| Two 285-K.W. and two 30-K.W. generators | 5,200.00 |
| Station wiring and instruments | 1,900.00 |
| | $38,100.00 |
| Nine miles (27 total) of circuit, 19.6 sq. mm., including poles and right of way | $11,000.00 |
| | $49,100.00 |

## HYDRAULIC DEVELOPMENT AT WEST BUXTON, ME.

*Abstracted from The Engineering Record of July 27, 1907.*

THERE has been installed at West Buxton, about 20 miles west of Portland, Me., a 3,000-K.W. plant for the transmission of a three-phase, 60-cycle, 30,000-volt current to the Electric Lighting Company at Portland. It will be operated by hydraulic power devel-

FIG. 81.—DAM AND POWER-HOUSE.

oped in the Saco River and involves the construction of a dam about 300 ft. long, 33 ft. in extreme height, and 28 ft. in width at the base, a 100 × 100-ft. power-house, a 40 × 100-ft. dynamo-house with four 750-K.W. units, turbines and other machinery required, a 150-ft. boom, a log chute, and a 50 × 300-ft. tail race.

At the site the river has a width of 350 ft., an average depth of 3 ft., and a velocity of about 6 ft. per sec. at ordinary stages of the water. A 4-span highway bridge formerly crossed the river about 100 ft. below the present dam and slightly oblique to it, a crib dam

crossed the river about 50 ft. above it and connected at the east end with an old grist-mill and other buildings which occupied the site of the power-house.

The dam is approximately perpendicular to the shore line and

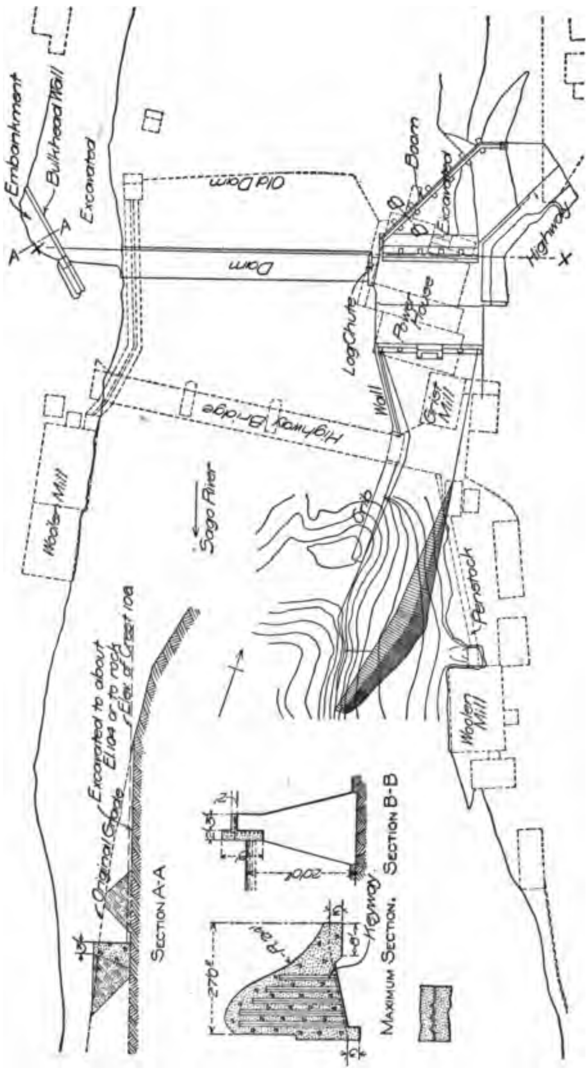



FIG. 82.—MAP OF WEST BUXTON DEVELOPMENT WITH SECTIONS.

has a standard cross-section with curved crest and ogee face downstream, a vertical face upstream, and a depressed footing or cut-off wall at both the up and downstream longitudinal edges of the foundation. The west end of the dam makes an oblique angle with a concrete abutting wall which it intersects and with which it is integral; the footings of this wall are carried down to rock and it has a maximum height of 10 ft. with a top width of 3 ft. It extends about 100 ft. upstream from the dam to intersections with the maximum flow lines of the impounded water and is carried up to a height of 8 ft. above the crest of the dam, thus concentrating all flow over the crest of the dam and protecting the bank on the downstream side. The wall was built in an open cut with 1 : 1 slopes and was back-filled on the shore side, the river side being left unfilled and excavated near the dam to a depth of 3 ft. below the crest. At the opposite end of the dam a sluice 11 ft. wide and 2 ft. deep below the crest is built to afford a runway chute for logs, and slopes rapidly downward to a point about 10 ft. beyond the lower face of the dam where it is below water-level. The sluice is integral on the river side with the dam and on the shore side with the outer wall of the power-house foundations. Normally, the sluice is opened, and the water discharged through it somewhat reduces the depth on the crest of the dam, but provision is made for closing it if necessary by stop planks fitting recesses in the side walls near the upper end.

The power-house foundations are of concrete up to a level 7.5 ft. above the dynamo floor, above which the structure is entirely of brick and steel except on the side toward the turbine chambers, which are separated from the dynamo room by a concrete wall extending 8 ft. above the crest. The floor of the dynamo room is 13 ft. below the crest of the dam; and in order to provide for a possible flood such as was caused by an ice gorge eight years ago, the windows and doors are $7\frac{1}{2}$ ft. above the floor, and the walls are made reasonably tight up to that height. Water is admitted to the turbine chambers through five rectangular 16 × 16-ft. openings between the four longitudinal interior foundation walls which are

extended about 23 ft. beyond the intake gate to form piers with slightly inclined cutwaters and which rest on a concrete foundation on the solid rock 22 ft. below the crest of the dam. The piers support on their upstream faces a continuous reinforced concrete girder with an irregular cross-section about 8 ft. deep and 7 ft. wide, having its lower surface 2 ft. below the crest of the dam to form a sort of boom to intercept any floating material and also a support for needles for closing any penstock above the gates, as well as making foundations for a future house over gates, hoists, and screens. A depressed walk $2\frac{1}{2}$ ft. wide and 3 ft. above the crest of the dam provides a platform from which it is easy to push the débris along the face of the boom and from which needles may be placed. About 7 ft. in the clear, downstream from this girder there is a second thin horizontal girder supported on the piers and extending across the full width of the power-house. It has a horizontal and inclined surface forming the bottom and one side of a trough opening into the log chute. The downstream side of the trough is vertical and is

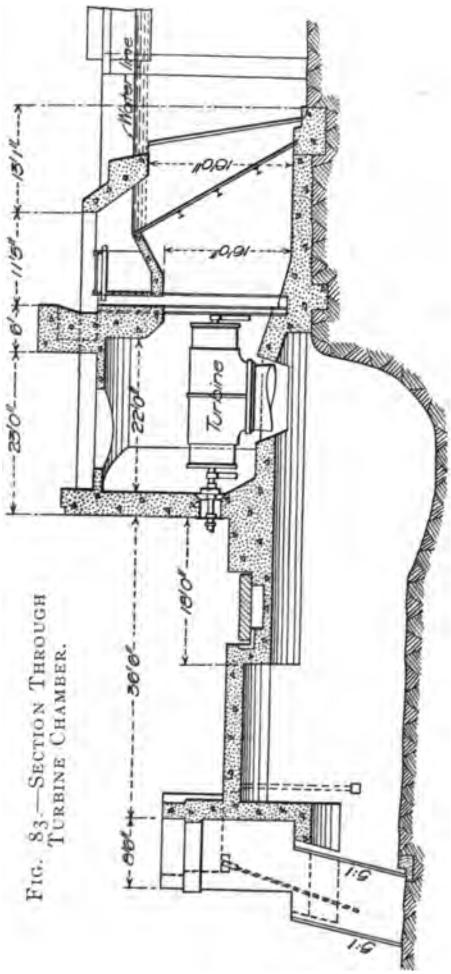



FIG. 83.—SECTION THROUGH TURBINE CHAMBER.

formed by horizontal planks separating it from the gates. The upstream edge of the trough is at the level of the dam crest and forms a support for the inclined rack-bars 23 ft. 3 in. long and 2 in. apart on centres. The feet of these bars take bearings on a concrete footing

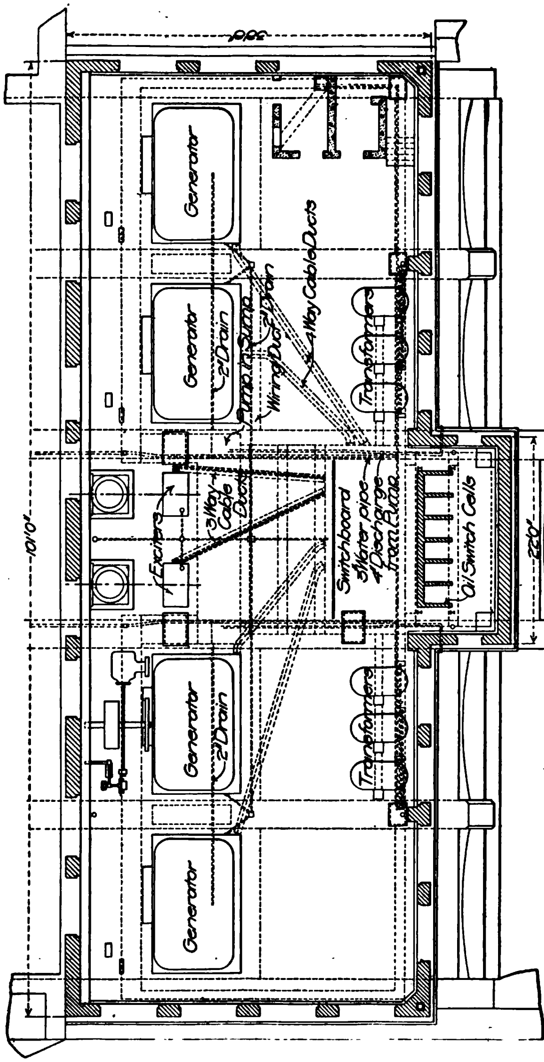



FIG. 84.—PLAN OF POWER-HOUSE.

and they are intermediately supported by three lines of equidistant horizontal I-beams. A timber platform is carried by transverse I-beams 4 ft. above the top of the trough and permits an attendant easily to float the ice which may accumulate against the masonry or rack over the edge of the trough and thence push it or allow the current in the trough to carry it down to the log sluice.

The floor of the turbine room is made with massive concrete arches without reinforcement which are 2.5 ft. thick at the crown and are carried by the 3-ft. longitudinal interior walls in the plane of the outside piers above mentioned. The tops of these walls are pitched both ways from the centres to the springing line so as to give radial surfaces for the skewback bearings. The footings of these walls are carried down 39 ft. below the crest of the dam, or 1 ft. below the level of the main excavation. The roof over the turbine room is similar in construction to its floor, but the arches are only 1 ft. thick at the crown and are pierced over the centres of the turbines with large circular holes closed with doors made with two crossed courses of planks. This floor forms an open platform between the front wall of the dynamo-house and the gate-hoist foundation which is a hollow concrete parapet 6 ft. wide and 7 ft. high.

The entire area of the dynamo room is commanded by a travelling crane of 34½ ft. span, and 15 tons capacity, with its rails 5 ft. clear of the lower ends of the roof beams. These latter are 20-in. deep, spaced 7 ft. 8 in. apart on centres and are pitched about 1 in 36. They carry a continuous 4-in. slab of concrete, reinforced by No. 10 expanded metal with 3-in. meshes which is covered with tar and gravel.

The intakes are closed by vertical wooden gates made of 4-in. horizontal planks with pairs of 8 × 10-in. vertical lifting beams bolted, keyed, and X-braced to them and provided with cast-iron racks engaging pinions operated by hand from the deck above. Many logs are run down the river and are diverted from the powerhouse by the main boom which extends from the log sluice to the river bank at a point about 110 ft. upstream, thus making an angle

of about forty-five degrees with the face of the power-house and facilitating the movement of logs and other drifting material to the sluice. It is a horizontal concrete girder with a T-shaped cross-section 8 ft. deep and 5 ft. wide with vertical and horizontal webs respectively 2 ft. and 1 ft. in thickness. The vertical web is reinforced by 19 rods with areas of 1 sq. in. spaced 5 in. apart, lapped 2 ft. at joints and located 2 in. from the downstream face of the beam. The horizontal web is reinforced by six bars each with an area of .62 sq. in. spaced 6 in. apart, lapped 13 in. at joints and located 2 in. above its lower surface and forms a walk. The booms are supported on concrete piers 4 ft. thick, with both sides battered 4:1 and nearly 23 ft. apart on centres. The girder is made continuous with three-panel lengths and butt joints for expansion on the centre line of the centre pier, the river abutment, and the last pier at the shore side.

The existing dam, over 100 years old, was made with cribs filled with stone, and, although in excellent preservation, was so leaky that all the silt and sediment had washed through it from the pond above. It was made tight with sand bags put in place by divers, and the crest was raised 5 ft. with flash boards supported on triangular wooden frames, the west end being torn out to take the flow. A low earth dam or dike, sheeted on the lower side, was built nearly across the river below the site of the new dam, and the river diverted to a channel near the west bank by a cofferdam 200 ft. long on the east side of the channel parallel to the shore line and connecting the old dam and the dike below. It was made with timber cribs 15 ft. high, 12 ft. long, and 16 ft. wide floated to place, filled with sand, and sheeted with 3-in. tongue-and-groove vertical planks. The area between the dams was drained and kept dry with a single pulsometer and a 6-in. steam pump. The surface of the granite rock was found smooth and regular, but, on account of the deep seams it contained, was excavated with steam drills and dynamite to a depth of 4 to 8 ft. for the footings of the new dam.

A concrete platform 33 ft. above the river bottom was built on falsework trestle bents at the level of the highway on the east

FIG. 85.—INTERIOR OF WEST BUXTON POWER STATION.

bank of the river. Stone from the excavation was broken and stored in a 1,000-yd. pile on the opposite side of the road from the platform, where sand and gravel were also delivered by wagons. Cement was stored in adjacent buildings, and all of the material was delivered by wheel-barrows to the centre of the platform, where they were measured and chuted through trap-doors to two mixers under the platform which delivered the concrete to 1-yd. bottom-dump steel buckets on flat cars on a 2-ft. track on a service platform about 400 ft. long and 16 ft. above the bottom of the river. The concrete was delivered to six guyed derricks with 5-ton, 60-ft. booms which commanded the entire length of the dam and handled the forms and all materials. They were operated by double drum engines and handled a maximum of about 200 yds. of concrete daily.

The concreting was carried on without interruption during the coldest weather and when the temperature was as low as minus 47°. The only precautions taken were to mix the concrete with hot water and to soak the broken stone in a hot-water tank large enough for two 1-yd. skips and heated by exhaust steam from the steam-engine and live steam from the hoisting-engine boilers. Although the sand was used cold, the concrete was so hot when first mixed that sometimes the men could scarcely walk in it with rubber boots. It was covered at night with tarpaulins and in the morning was found still moist and unfrozen.

The dam was made in alternate sections 40 ft. long, bonded together with four vertical triangular 12 × 12-in. keys 18 in. apart in the clear. They terminated 2 ft. below the upper surface of the dam.

Derrick stones up to 1 yd. in volume were bedded in the concrete and formed about 30 per cent. of its mass. Care was taken in filling the moulds to complete a horizontal course over the whole surface each day, a requirement which necessitated the men sometimes working from 12 to 14 hours; corresponding heights of from 3 to 8 ft. a day were secured according to whether the work was at the base or the top of the dam. Successive courses were bonded together by large stones embedded in the surface so as to project half-way above the top of the lower course and tooth with the upper

course. The forms were built of 2-in. square-edged dressed pine planks and were not interchangeable, being knocked down as each one was stripped and rebuilt for the next.

The main generators are of the revolving-field type and are

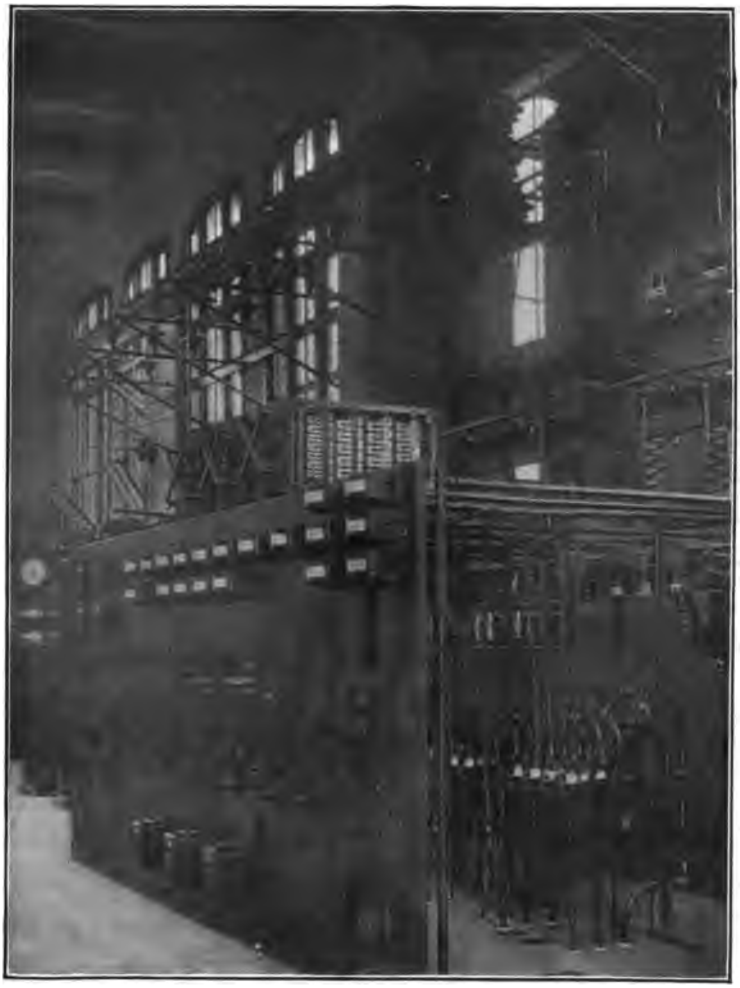


FIG. 86.—SWITCHBOARD.

designed to carry an overload of 25 per cent for two hours without excessive overheating. They have a full-load efficiency of 94 per cent. and an efficiency of 91 per cent. at half load.

The switchboard and transformers, in two banks of three each, are arranged in a row opposite the generating machinery. The transformers are rated at 500 K.W., and are oil-insulated and water-cooled. The cooling water is circulated through a coil in the upper part of the transformer tank over the core and surrounding the ends of the windings. The water is taken from the fore-bay, near the exciter turbines, and carried beneath the floor in two 3-in. pipes, which are connected by a third 3-in. pipe running crosswise under the transformers. This cross pipe is connected with another lateral pipe lying close to the transformers, by risers in which are placed suitable screens. One-inch pipes lead directly to the respective transformers from the secondary lateral pipe. A glass is provided in the water circuit of each transformer so that the circulation is always under observation. From the transformers the discharge pipes lead downward into the tail-race.

The switchboard and apparatus are designed for a current capacity commensurate with the 22,000-volt transmission pressure, and automatically operated oil switches are used on the outgoing lines. There are nine principal panels as follows: One exciter panel, one regulator panel, four three-phase generator panels, one transformer panel, and two outgoing line panels.

The design of the West Buxton plant, and in particular the transmission system, is based on the purpose of ultimately uniting the service with that of the Great Falls water-power plant at a main transformer station in Portland. The transmission lines from the Great Falls plant are to be carried direct to the new station. This will permit the abandonment of several substations and auxiliary plants. The high-tension current from both West Buxton and Great Falls will be reduced to a uniform pressure of 2,300 volts for transmission to the Consolidated Electric Light Company's plant. There, motor-generator sets are placed for converting the united output to direct current at 250 volts, which

is distributed by a three-wire system throughout the business section of the city. At present there are installed at the main transformer station mentioned six 500-K.W., 22,000/2,300-volt self-cooled units, with provision for further transformer equipment to handle the Great Falls output.

The transmission line from the West Buxton plant to Portland consists of two three-phase circuits of No. 2 wire, a metallic tele-

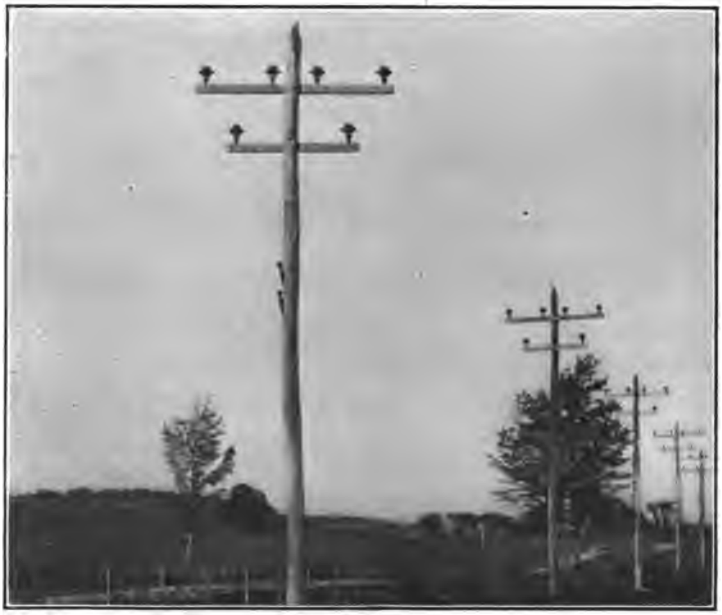


FIG. 87.—TRANSMISSION LINE.

phone circuit of No. 12 copper wire, and a ground circuit of No. 12 phono-electric wire. The main-line insulators are triple petticoated glazed porcelain, and are mounted on hard maple pins. The circuits are carried one on either side of the pole on two cross-arms, and the triangles are inverted. The wires are placed 36 ins. apart. The telephone wires are carried on brackets below the lower arm, while the ground wire is run over the tops of the poles

and grounded at every sixth pole through a No. 4 B. & S. copper wire, connected by a brass screw-plug with a galvanized-iron pipe driven 6 ft. in the ground. The cross-arms are of long-leaf yellow pine, and are doubled at points of curvature on the line. The poles are "butt-cut" chestnut and vary from 35 ft. to 60 ft. in length, having a minimum diameter at the top of 8 ins. The spacing is 100 ft. on tangents.

## THE HYDRAULIC POWER DEVELOPMENT OF THE ANIMAS POWER AND WATER COMPANY.

*Abstracted from The Engineering Record of April* 14, 1906.

THE Animas Power and Water Company was incorporated in Colorado for the purpose of building irrigation canals, reservoirs, and developing water power. The first work of importance undertaken by the company was the building of the Animas power plant, which is located on the Animas River and a branch of the Denver & Rio Grande Railroad, about half way between Durango and Silverton, just above the Animas Canyon.

The power-house is a 108 × 64 foot brick and concrete building with a roof of steel and concrete, making it as nearly fireproof as possible. The building was erected to accommodate four units, only two of which are at present installed. The others are to be put in later. The leading features of the building are shown in the cross-section and photograph (see Figs. 91 and 92). The company has at present contracts for more than 4,000 H.P.

The power is derived from water taken from Cascade Creek and the watershed tributary to the large reservoir. Cascade Creek has a flow of 3,720 cubic feet per minute and the watershed of the reservoir has 1,500 cubic feet more, making a total available water supply of 5,220 cubic feet per minute. The water is diverted from the creek and runs through a wooden flume $3\frac{1}{2}$ miles long, which is 6 × 8 feet and laid on a grade of 0.2 per cent. From the flume

water flows into a natural water-course and empties into a reservoir, which has an area of 960 acres.

The reservoir was made by building a stone-and-timber dam about 750 feet long and 55 feet high, with a foundation 33 feet deep to bedrock. It is proposed to replace this dam by one of concrete 100 feet high and about 1,400 feet long. This will increase the area of the reservoir to 1,161 acres. When the concrete dam

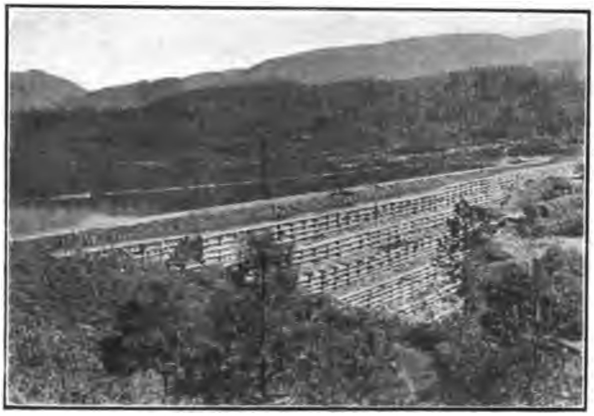


FIG. 88.—ANIMAS DAM.

is built, the company expects to take the water from Lime Creek into the reservoir, which can be done by building another flume 4 miles long. When the water from Lime Creek is added, the available water supply will be double. or 10,440 cubic feet per minute. At some future time, as the demand for power increases, it is proposed to use the water from the Animas River. In order to accomplish this, it will be necessary to build a tunnel 8 miles long, and when this is done there will be sufficient water for developing some 38,000 H.P.

From the reservoir the water is taken in a 38 × 56 inches wooden flume 8,800 feet long, laid on a grade of 0.25 per cent., which empties into an intake reservoir. The intake reservoir has an area of about five acres. Its dam is of earth, with a

12

concrete core wall 3 feet thick and another concrete wall at the inner toe. At present it is 30 feet high by about 100 feet long, but it is to be raised 10 feet, which will give an effective head of 970 feet at the power-house.

The pipe enters the intake reservoir 25 feet below the surface of the water, thereby avoiding any possibility of ice entering or blocking the pipe. In front of the pipe is located the usual screen made of flat bars of steel. The end of the pipe is tapered to 60 inches in diameter; where it emerges from the dam it is 44

FIG. 89.—ANIMAS FLUME.

inches, and has a gate valve and a 10-inch standpipe on the lower side to admit air, so as to prevent any danger of collapsing the pipe in case the valve is rapidly closed. The standpipe passes through the gate-house and is enclosed in a wood flue. The heat from a stove in the gate-house passes through the flue and around the standpipe to prevent the water in it from freezing.

It would appear that nature had intentionally left an opening in the cliffs for a pipe line to come down from this reservoir to the power-house. Starting at the top, where the elevation is 987 feet

above the station, the pipe is 44 inches in diameter by 3-16 in. thick and runs for some 800 feet, on a slight grade over the mountain to a point where the head is 125 feet and the pipe is thickened to ¼ inches. From this point downward the metal in the pipe increases

FIG. 90.—PIPE LINE AND POWER-HOUSE.

in thickness to 11-16 inches and the diameter changes to 40, 36, and 34 inches, there being an equal quantity of each diameter. The pipe is 2,842 feet long and is double riveted in the longitudinal seams and single riveted in the girth seams, down to 560 feet head.

From this point it is double riveted in the longitudinal seams and single butt-strapped and single riveted in the girth seams down to a point where the head is 975 feet, and from there to the bottom the pipe is double butt-strapped and triple riveted in the longitudinal seams. The riveted joint efficiency is 82 per cent. The pipe is made up in sections 30 feet long and fitted with welded steel angle flanges. The flanges are bolted together with combination copper and lead gaskets between them. The gaskets are made with one ring of ⅛-inch copper wire just inside of the bolts, then comes a lead ring 3-16 inches thick, and inside of this a 5-16 inch lead ring. The three rings are held together in places by solder and make a very substantial and perfectly water-tight joint. The heaviest sections of pipe weigh six tons each. The steepest grade on the line is 84 per cent.

At the power-house and lower bends the pipe is thoroughly anchored in large blocks of concrete, each of sufficient size to carry the weight of the pipe above it. The sections of pipe at the lower end were tested to 650 pounds per square inch before leaving the shops of the company, which furnished the piping and water-wheels. The pipe was hauled up the hill with a mine hoist and cable, and the grade was so steep the cable could not be loosened from a section until it was in place.

At the lower end of the pipe line there is a cast-steel Y, tapering down to two 20-inch branches fitted with gate valves having by-passes, and roller bearings connecting to the 20-inch by-pass needle nozzles of the wheels. The nozzles are arranged with a system of toggle levers by means of which the water can be turned from the wheel through the by-pass. These toggles are arranged so that, for a uniform rotation of the governor shaft, the variation in power delivered to the wheel will be constant. The by-pass is used in order to prevent shock to the pipe in case the load is suddenly thrown off the generator. The needle which controls the supply of water to the wheel and the one to the by-pass are connected by means of a right-and-left-hand screw so that their relative positions can be changed at will by means of a hand wheel. This hand

wheel can be set by the aid of a predetermined load curve and reduces the waste from the by-pass water to a minimum.

The wheels are 8 feet overhung Pelton wheels one on each generator shaft, with a normal capacity of 3,000 H.P. each at 300 r.p.m., but capable of being run up to 4,000 H.P. The wheel centres and the buckets are made of cast steel. Each bucket is bolted to the wheel centre with one $2\frac{1}{4}$-inch and one $1\frac{3}{4}$-inch bolt, giving ample strength to permit the wheel being locked and full

FIG. 91.—3,000 H.P. PELTON WHEELS AND GENERATORS.

stream turned on or allowed to run as fast as the water will drive it with no load on. The shafts are fourteen inches in diameter at the bearings and 16 inches at the rotors or fields. They are hollow, with 5-inch holes through which water is made to circulate to assist in keeping the bearings cool. The bearings are $14 \times 42$ inch water-cooled, and are babbitted in lower half only.

The wheels are controlled by oil-pressure governors with two pumps, arranged so that one can furnish power for either or both governors.

The generators are of 2,250 K.W.-capacity, and of the revolving-field, three-phase, 60-cycle type, with the exciter armature mounted on the shaft. The generator voltage is 4,000, with step-up transformers and line voltage of 50,000.

There are six water-cooled oil transformers of 750-K.W. capacity each. Each transformer is located in an iron-and-concrete vault, completely closed, so that in case of fire the oil cannot burn and damage any of the other apparatus.

The switchboard gallery is located over the transformer vaults.

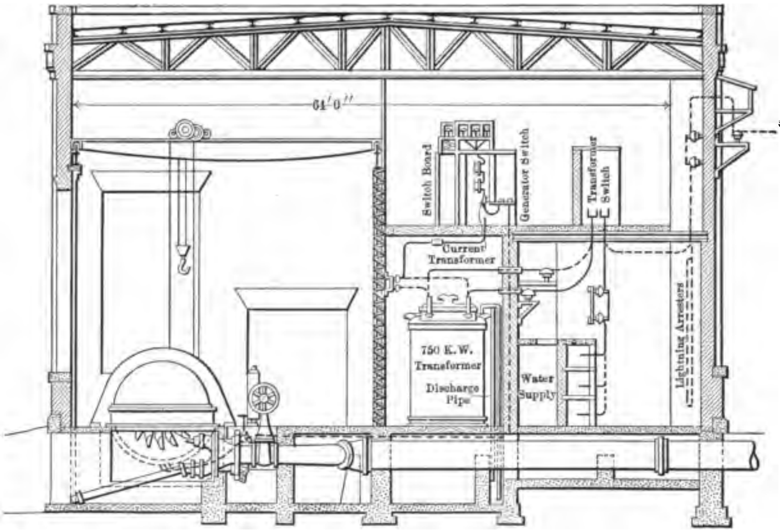



FIG. 92.—CROSS-SECTION OF POWER-HOUSE.

The generator mains run up through brick chambers to the oil switches and circuit breakers and then to the generator bus-bars. From the bus-bars the circuit passes down to the transformers where the current is stepped up to 50,000 volts. The circuits then go to the high-tension oil switches and circuit breakers, and from there to the transmission line. The switchboard is located near the front of the gallery and fitted with the usual instruments, together with a voltage regulator. The operator in front of the switchboard has all of the machinery in full view.

The transmission line is built of three cables, each composed of six No. 8 B. & S. aluminum wires with a hemp core and a conductivity equal to No. 2 B. & S. copper. The cables are arranged

on the cross-arms so as to form a triangle with 6-feet sides. The poles are pine, 36 feet long, and set 6-feet in the ground 250 feet apart. The longest span is 1,100 feet, where the cables stretch between wooden towers and span an arm of the reservoir. There is a substation in Silverton with transformers for stepping down to 17,000 volts.

## HYDRO-ELECTRIC PLANT OF THE CITY OF DRAMMEN, NORWAY.

*Abstracted from the Electrical Review of May* 12, 1906.

For supplying light and power to the city of Drammen and the surrounding country on the Drammen Fjord, located some twenty miles southwest from Christiania, the water of the Storelven was dammed at the waterfall "Gravfos" and utilized in the power-house located at the junction of the Storelven (the upper part of the river Draven) and the Suaramselven, some twenty miles above the city of Drammen. Preliminary to the construction of the power plant it was necessary to build a branch of the Drammen-Randsfjord Railway from Gjeithus and connecting from the end of this branch to the plant by way of a steel bridge over the "Gravfos."

About 65 metres (215 feet) above this fall a concrete dam is constructed, with the intake canal at the left of the river-bed, provided with six main sluice gates operated from a gallery above the intake. Connecting with this canal is a tunnel 230 feet long and 10 metres (32.8 feet) wide at the bottom with an arched roof cut in the mountain. On account of the softness of the rock it was found necessary to line this tunnel for a distance of 27 metres (88½ feet) with brick. This tunnel leads into the collecting basin, which it was also found necessary to line with masonry. The tunnel enters one side of the collecting basin, while on the opposite side are two pressure tunnels, there being space for a third one. One of the ends of the basin is provided with an overflow and sluice gate to drain the basin in case of an

emergency. All sand and gravel carried down to the basin is removed by a sand trap through the overflow channel. The sand-trap gates and also the emergency gates are operated from a point on top of the wall of the basin. Sluice gates are installed in the pressure tunnels, only one of which is at present in use. These tunnels are 4 metres (13.12 feet) high and 4.25 metres (13.94 feet) wide and are lined with masonry. Two turbines are connected to this tunnel by means of two short steel branch penstocks, leading from one main penstock, and a third branch penstock leads to the two exciter units.

As the available water supply was 30 cu. meters (1056 cubic feet)

FIG. 93.—POWER-HOUSE.

per second with a net fall of 14.5 metres (47.5 feet), a development of 4,400 H.P. was possible. This energy had to be transmitted over a distance of 35 kilometres (21 miles) and distributed to two harbor cities spread along the shores of the fjord. The plant was designed to generate three-phase alternating current at a potential of 5,000 volts, which is stepped up to 20,000 volts and then transmitted to the

city entrance of Drammen, where this secondary current at 18,000 volts is transformed down to 4,500 volts. From here the current is distributed to a number of smaller transformer substations, where this 4,500 volts is again stepped down to 220 volts, at which

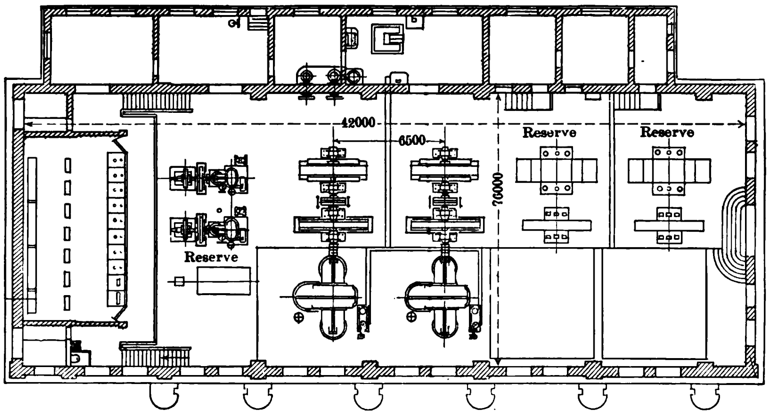



FIG. 94.—PLAN OF POWER-HOUSE.

potential the consumers are supplied. The feeder systems are installed partly overhead and partly underground. From the foregoing it will be seen that the installation includes a generating station, a step-up transformer system, a long-distance high-tension transmission line, a step-down transformer station, a high-tension distributing system, step-down transformer substations and low-tension distributing systems. The hydraulic plant is designed for four main units and three exciter units, having at one end space for the switchboard and step-up transformers. The total length of the plant is 42 metres (137.7 feet) and the width 16 metres (52.4 feet) with an extension on one side containing offices, storerooms, pump-room, and a repair shop. The entire building up to the generating-room floor is of concrete, while the upper part is of brick. The roof trusses are of steel covered with wooden planking and corrugated steel. A 50-ton overhead crane travels the length of the generating-room, but not over the

switchboard. As already stated, the plant is designed to accommodate four main units, although only two 900-H.P. units are at present installed and two 66-H.P. exciter units.

Before entering the building the penstock is divided into two parts, each of 2.1 metres (6.88 feet) diameter, each supplying one of the main 900-H.P. units. In addition to these there is another third branch 1 metre (3.28 feet) in diameter supplying the exciter units. Each of the main pipes is equipped with a butterfly valve. To operate these butterfly valves electric motors are installed in the pump-room, while the valve of the exciter penstock is operated by hand. The main turbines are built on the double-wheel Francis type, making, with a head of 14.5 metres (47.56 feet) and 214 r.p.m., 900 effective H.P. Each turbine unit is

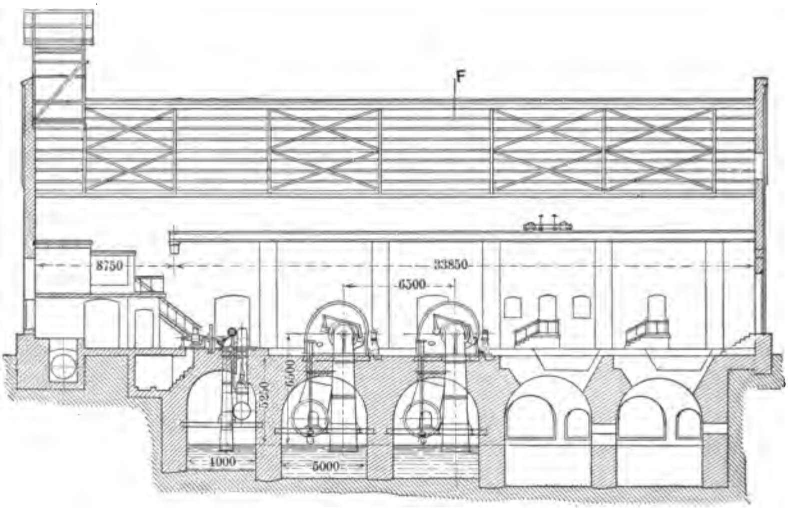



FIG. 95.—LONGITUDINAL SECTION OF POWER-HOUSE.

provided with a flywheel. Between the turbine and flywheels is a clutch coupling. Each turbine is well provided with hydraulic governing devices. For switching the turbines in multiple the operation of the governor is controlled from the switchboard by an electric motor mounted on the side of the governor.

The pressure water needed for the governor is supplied by two 7-H.P. electrically operated pumps installed in the above-mentioned pump-room together with the necessary accumulator.

The exciters are also driven by Francis turbines, but of the single-wheel type. These turbines are also equipped with fly-

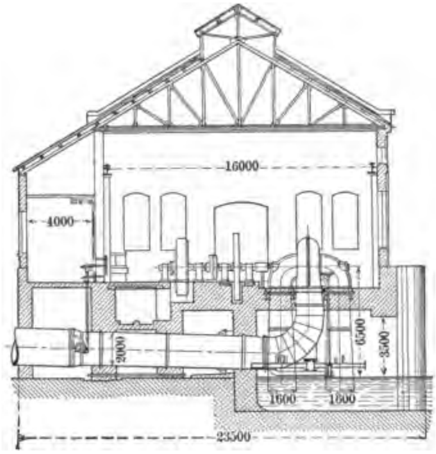



Fig. 96.—Transverse Section of Power-house.

wheels forming part of the coupling between the turbine and generator. The couplings are not of the rigid type, but are insulated flexible couplings. These turbines are also equipped with hydraulic regulating mechanism, but the pressure, however, is supplied by the head in the penstock, thus avoiding the necessity of pumps, as is the case with the main units. The small turbines, with maximum water supply, have an efficiency of 75 per cent, while the main units under the same conditions have the same efficiency. With 0.8 load the efficiency is 71 per cent and with 0.6 load, 70 per cent.

With a sudden decrease in load from full to no load the variation in speed will not exceed 15 per cent, while with a variation of 25 per cent in load the flywheel holds the variation in speed down to only 2 per cent.

The alternators are of the Oerlikon type, 750 K.W., 5,000 volt three-phase, 50 cycles, and are coupled to the turbine shafts by means of insulated, flexible belt couplings. The magnet frame is in two parts, divided horizontally, with laminated poles bolted to the frame. At full load and power factor = 1 the efficiency is 94 per cent, while with power factor = 0.8 the efficiency is 93 per cent. In decreasing from full load to no load the potential increase in the former case is 7 per cent and in the latter case 15 per cent. The above figures allow for the energy of excitation, which at full load is 7 K.W. with power factor = 1 and 13 K.W. with power factor = 0.8. The maximum temperature increase after a 24-hour full-load run does not exceed 40° C. The 64-K.W. exciter sets are 110-volt, shunt-wound, direct-current-generators, each connected by a flexible coupling to the flywheel of its turbine shaft, as already mentioned, and operate at 650 r.p.m.

From the generators to the switchboard, cables are laid in a tunnel below the floor, three, 70 sq. mm., iron-bound, lead-covered cables leading from each machine.

The switchboard is placed on the end wall of the plant and is two stories high, the lower part on the generator-room-floor level being occupied with the transformers and rheostats, while the upper part is taken up with high-tension (20,000 and 5,000 volt) fuses, switching devices, measuring instruments, etc. Above this is a small gallery where are located the bus-bars and horn lightning arresters. The switchboard is completely equipped with the most modern apparatus and the entire wiring layout made with a view to convenience, flexibility, and simplicity. The current from each generator is measured, and the total current supplied to the 5,000-volt bus-bars again measured by recording instruments before feeding the step-up transformers. Current at 20,000 volts is then led out over a line protected by two horn lightning arresters, on each phase arranged in parallel, and also choke coils. In addition to this, a continuous flow of water prevents the potential from rising above 20,000 volts. If the potential exceeds this amount it is grounded through the water.

For switching the generators in parallel a voltmeter switch, a phase voltmeter, and synchronizing lamp are provided. A small regulating motor is controlled from the switchboard.

The switchboard is designed to accommodate the complete installation, although at present the apparatus for only two units

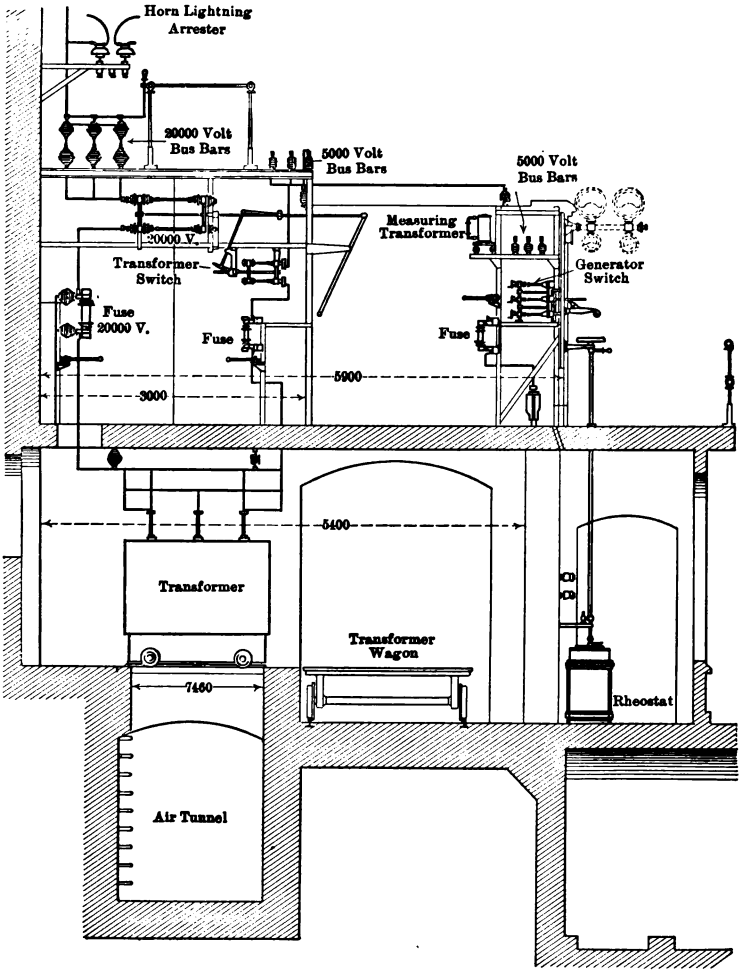



FIG. 97.—SECTION THROUGH TRANSFORMER AND SWITCH ROOM.

and the auxiliaries is installed. The board is made of white marble, mounted on an iron frame.

The switch system for the transformers consists of two separate systems, one for 5,000 volts lying in the generator-room, and the other for 20,000 volts in the transformer-room. The transformers are mounted on wheels, so that they may be moved onto low platform cars and carried into the repair shop. An air duct extends under the transformers for ventilation, with a motor-driven fan at the end.

The feeder system is designed to transmit 1,800 H.P. with a drop in potential of 11 per cent. The length of the feeder system is about 21 miles and consists of three hard-drawn copper wires with a sectional area of 25 sq. mm.

The common method of carrying these wires is on wooden poles having three cross-arms in order to carry six insulators for two systems. Three insulators only, are at present in place. They are so placed that each cross-arm has one insulator. This is done in order to allow a turn of one-third in the relative position of the feeders, which takes place once in three and one-half miles, so that in the whole run the cables are twisted twice. The poles are placed about 210 feet apart. In crossing streets, streams, etc., protective wire nets are placed under the feeders, so that a broken wire may not drop to the ground.

Wooden poles are used throughout most of the run; lattice-work iron poles, however, are used in several cases. These poles are of the requisite height and are thoroughly creosoted and protected by cast-iron caps. The wires are carried on delta-shaped brown porcelain insulators bolted to the cross-arms. The cross-arms are braced by angle irons. Below this high-tension, 20,000-volt system for a certain distance is carried the 5,000-volt feeder on porcelain insulators mounted on iron brackets. Twenty-six inches below these are placed the telephone lines. Ten sectional cut-outs are installed, enabling the operator to disconnect certain districts. At the crossing, over the railway, a roofed steel structure is provided to carry the feeders.

There is at present one transformer station for reducing the potential from 18,000 to 4,500 volts. On entering the station the wires are equipped with two parallel switches and horn lightning arresters for each phase. In connection with the arresters there is an induction coil in each phase. From the substation, three cables and one air line lead out at a potential of 4,500 volts for the high-tension distribution system. A small auxiliary transformer is installed to furnish power at 220 volts for lighting the station and to operate the transformer blower. As the transformer station is a three-story building; the main floor contains the transformers, blower, etc., the second floor the switching system for the outgoing feeders, and the third floor the lightning arresters for the incoming and outgoing feeders. The transformers are of the same design as in the main power-house.

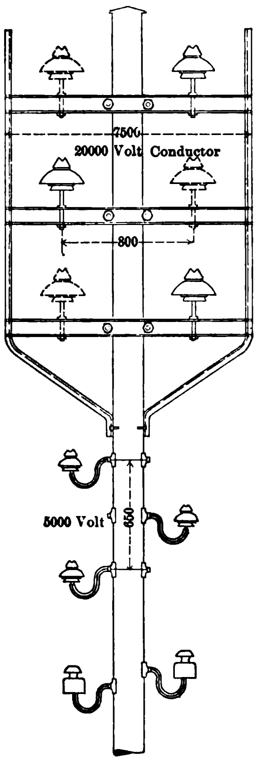


FIG. 98.—POLE-HEAD.

The high-tension distribution system leads to two transformer substations being carried on the same poles as the high-tension transmission line. The wire is 20-sq. mm. hard-drawn copper, mounted on brownglazed porcelain insulators. The greater part of the high-potential distribution system is that carried underground on cables for about eight miles. From the substation two cables run to each of the two halves of the city on the opposite side of the river and fjord. These cables are paper-insulated in a lead sheathing, filled with jute, and iron bound. At the sub-transformer stations the potential is stepped down from 4,500 to 220 volts. There are altogether, 14 tiansformer stations, 12 of which are in

the form of cylindrical steel towers about 5½ feet in diameter and some 20 feet high, while the two others are of brick. The former stations rest upon solid concrete foundations and are provided with doors to give access to the different apparatus. Special care is taken for good air circulation; the air entering at the bottom rises and is discharged below the top hood.

The high- and low-tension systems are, of course, distinctly separate, and so also are the light and power systems. In order to simplify the wiring as much as possible, the three high-tension bus-bars, which are of aluminum, are mounted directly on the fuses. On the low-tension side, the feeders run down to a three-pole knife switch and to the fuses. Here, also, the bus-bars are mounted directly on the fuses. The iron frame of the stations as well as the transformer frames are positively grounded with a copper wire.

The masonry buildings are made of rough stone and well supplied with natural light and also designed for air circulation. The wires of the 4,500-volt system enter the station through glass plates, passing through induction spools and fuses to the transformers. The system is protected by three, horn lightning arresters. The other equipment is the same as for the iron towers.

The low-tension distributing system consists of overhead air lines and underground cables, the latter being laid in trenches 28 inches deep and covered by tiling. The overhead lines do not run directly from the transformer stations, but are connected from the underground feeders, at which points, small iron latticed poles are erected. These poles are surrounded by an iron sheathing 6½ feet high, provided with a door to give access to the fuses, etc. From the fuses the feeders rise to the top of the pole, which is also surrounded by sheet iron behind which the induction coils are arranged. The lightning arresters are installed outside of this casing. The arresters and towers are grounded by a common copper wire. From these distributing towers the wires lead to the various consumers.

# THE GREAT FALLS STATION OF THE SOUTHERN POWER COMPANY.

*Abstracted from the Engineering Record of May 18, 1907.*

The Southern Power Company owns or controls in all nine water-power sites in the so-called Piedmont Section, embracing the sand-hill district extending from the foot of the Blue Ridge mountains to the fall line, a distance averaging probably 120 miles. One capable of development for 12,000 H.P. lies on the Broad River of the Carolinas equidistant from Gaffney and Blacksburg, S. C., while another is located on the Wateree River, of which the Catawba River is the principal tributary. This one is capable of development for 20,000 H.P. All others are on the Catawba River. The aggregate of these powers will amount to 145,000 H.P., which will be transmitted to cover a territory over 150 miles long and about 100 miles in width.

*The Great Falls.*—The Great Falls of the Catawba consists of a series of falls and shoals having a total head of 176 feet in a distance of about 8 miles, the development of which will require three separate plants.

The lowest of these necessitates the construction of a dam across the river just below the mouth of Rocky Creek, at which point there is available a drainage area of 4,450 square miles; a development of 60 feet is here feasible, which head backs water to the elevation of tail water in the middle development.

The highest development with a drainage area of 3,900 square miles will be effected by the construction of a dam immediately above the mouth of Fishing Creek. This plant will operate under a head of 40 feet, and its tail-water elevation will correspond to head water for the middle development.

The middle development with a head of 72 feet receives the run-off from the drainage area of 4,200 square miles, and is known as the Great Falls Station, the subject of this description.

From observations made under various auspices it has been

deduced that although the minimum flow of the rivers in this particular locality averages about ½ cubic foot per second per square mile of drainage area and for eight months in the year about ¾ cubic foot may be depended upon, the flood volume against which precaution must be taken in design is somewhat below 50 cubic feet per second per square mile, such flood-water flow being an exceedingly high one, and, it is thought, the greatest on record with the U. S. Geological Survey.

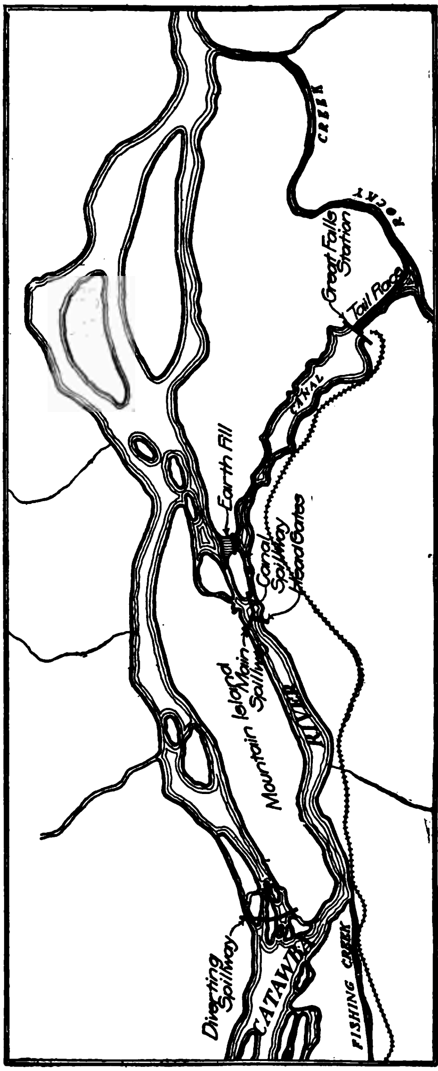



FIG. 99.—MAP OF SOUTHERN POWER CO.'S DEVELOPMENT.

This development consists essentially of a low spillway dam at the head of Mountain Island to deflect the water into the western channel. Flowing through this channel nearly to the foot of the island, it is then forced through the head-gates of the canal by another spillway dam. An extension of this dam serves as an overflow weir between the canal and the river. From this point the stream is carried by a canal through a natural valley about 1¼ miles to the power-

house and retaining bulkhead built across the valley, while below the power-house the tail-race carries off the spent waters ¼ mile to Rocky Creek, in which channel it is again carried to the river-bed.

*Canal Head-works.*—The deflecting dam at the head of Mountain Island is an ogee section overflow dam only 7 to 8 feet high,

FIG. 100.—DIVERTING DAM AND CANAL SPILLWAY.

the fall utilized for this development occurring almost wholly in the western channel, and in the dip of the valley through which the canal is carried to Rocky Creek.

The main spillway at the head-gate works, 438.85 feet long on the crest line with an average height of about 30 feet, has a batter of 1:10 on the upstream face and an ogee downstream face. The corresponding width at the base of the section is about 41 feet. This spillway, in connection with the diverting spillway at the head of Mountain Island is designed to carry safely a flood overflow corresponding to 50 cubic feet per second per square mile of drain-

age area, which volume of flood water will cause overtopping of the crest of the dam to a depth of 14½ feet.

The curve on the downstream face was determined by plotting the parabolic curve for the average velocity of the film of overflowing water increased by an assumed initial velocity of eight miles per hour, and so fitting the masonry to this curve as to intercept the nappe, breaking the velocity near the top and thus insuring contact of the sheet of water on the entire downstream face. The weight of masonry was assumed to be 125 pounds per cubic foot. An upward pressure equal to two-thirds of the head at the heel of the section and decreasing to zero at the toe was assumed to exist, and there was also considered to offset this pressure the weight of the overflowing sheet of water tending to increase the stability of the dam. Under these assumptions the section shows a safety factor of two for the most severe conditions, with increasing stability as the conditions approach the normal stage.

The spillway in the canal, similarly designed, and 521.2 feet long on the crest, averages about 36 feet in height, corresponding to which height the base has a width of about 37 feet 9 inches. The crest of this weir is one foot higher than that of the main spillway and its length is such that, with the worst conditions of flood that may be predicted, it will, when overtopped to a depth of 8 feet, carry off all the water that the canal head-gates will vent.

These spillways, the head-gate masonry, and all heavy bulkheads were built of concrete masonry, in which are embedded displacement stones as large as could be handled by the derricks. All masonry is founded on bed granite of a close and uniform texture. Sectional forms were used to the greatest practicable height, the upper curve being then finished by hand and template.

The concrete was mixed largely in the proportions of one part of Edison Portland cement to two parts of sharp, creek sand obtained on the building site and five parts of crushed granite, the run of the crusher having been used throughout.

The head-gate masonry supports a set of coarse racks and has

in it ten ways 16 feet wide and 18½ feet high with full-centred arch tops. These gate openings are separated by piers 5 feet in width. This section, averaging about 45 feet in height, is 8 feet wide on top, and the downstream side is battered 3 on 1. The piers are extended on the downstream side to form buttresses, which are 5 feet wide, 3 feet long on a level with the top of the main wall, and

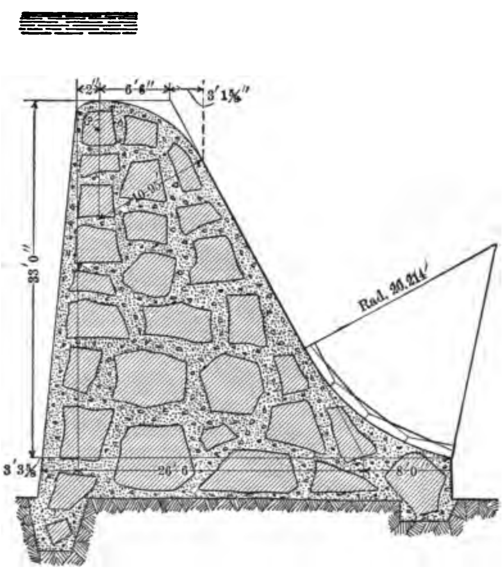



FIG. 101.—SECTION OF SPILLWAY OF MAIN DAM.

battered 2 on 1. Piers are also carried out on the upstream side for the support of the rack structure. These are 3½ feet long on top, this being 6 feet below the top of the main wall, and are battered 12 to 5, giving for the section a total width at the base of the gate opening of about 47 feet.

The gate frames secured into this mascnry are built of standard structural steel shapes. They are of the same dimensions as those used for the gates of the turbine intake flumes, and it was contemplated using the turbine head-gates in these frames for construction

purposes. Temporary gates were, however, later built of timber for this purpose.

In the event of placing gates in these frames it might become necessary to relieve the pressure upon them before raising, and for that purpose a by-pass has been built through this masonry at the shore end. The gate is of timber and is operated by a Smith gate hoist.

For the purpose of draining the low point immediately below these gates, a 4 × 5-foot sluice gate was built into the bulkhead, discharging below the spillway.

The racks protecting these waterways are coarse, being built up of ⅜-inch grid-bars, 5 inches deep, spaced 3 inches centre to centre, and separated by cast-iron spacers of such design as to prevent twisting of the bars under shock. These grid-bars are supported by a structural steel frame which in turn is supported by steel members built into the rack piers. This entire rack structure was designed of such strength as to withstand any pressures that might occur with a full head of water against a completely clogged rack. The racks were set on a batter of 12 to 5, so that logs and débris that might lodge against them should be forced to the top, whence they might be piked to a sluiceway 3 feet deep and 8 feet wide left in the spillway section for that purpose. There have been left in this sluiceway grooves for the accommodation of stop-planks should such economy of water become necessary.

*Construction of Head-works and Canal.*—The method employed in the prosecution of this work was, in general, as follows: Cofferdam No. 1 was built deflecting all the water to the deeper channel. The block of masonry marked *A* was then built. These cofferdams consisted of log cribs filled with stone and sheathed top and sides. The building of blocks *B* and *C* was then undertaken, whereupon cofferdam No. 2 was built, and when completed cofferdam No. 3 was built. Then all the head-gates, except those in the last two frames, were closed, and cofferdam No. 1 was opened and the water was vented through sections *E* and *F*. Temporary gates were then placed in the vent *E*, but a flood at this time tore out

the gate pier, and necessitated the building of cofferdam No. 4, within which this closure was effected. The two remaining head-gates were then placed in the frames, and, temporary gates having

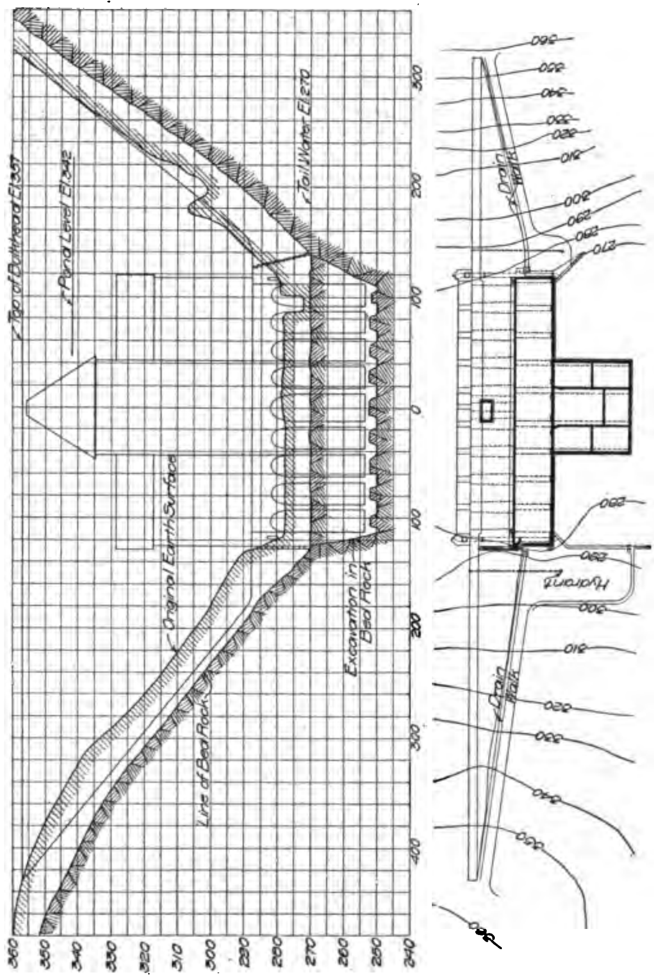


FIG. 102.—PLAN AND ELEVATION OF POWER-HOUSE.

been placed in the frames of vent *F*, the final closure was made. In making the closure, section *D*, nearly 200 feet long and containing about 6,000 yards of masonry, was built in nine days and nights.

For carrying the water from this point to the power-house it was necessary to excavate but little material to secure a hydraulic grade line from the bottom of the canal gates to a point 4½ feet lower at the power-house.

Such excavation as was necessary to secure a cross-section with a base of 100 feet and side slopes in rock of 2 to 1 and in earth of 1 to 2 amounted to but 195,000 cubic yards, for a total length 7,250 feet, and all of this material was necessary for filling in a gap existing between the valley and the river.

The site of the fill was prepared by clearing off all vegetable matter along a strip 100 feet wide, and on this strip a puddle of selected material was placed.

*Station Intakes.*—At the lower end of the canal the water is impounded by a concrete retaining wall or bulkhead having a width on top of 8 feet, a vertical upstream face and a downstream face battered 1.75 to 1, the height in the centre of the valley being about 90 feet. This section is largely increased in that portion opposite the power-house, for here there are built through the bulkhead the intake flumes for the turbines, the cases of which are also built into this masonry, and the power-house is built immediately below the bulkhead, forming virtually a part of it.

Through this masonry, carrying past either end of the power-house, there have also been constructed two trashways for by-passing leaves and small débris from the racks. These are 48 inches in diameter, built of riveted steel pipe and closed by sluice valves. Into these, by a manhole and check valve, there is also carried storm water off the side slope of the valley.

Before the water reaches the head-gates of the turbine intake it is against passed through a set of racks similar to those at the head of the canal, except that these are finer, the grid-bars consisting of ¼-inch bars 4 inches deep, spaced 1½ inches centre to centre. Provision has been made for the attachment of a power-operated rack-cleaning device, which will have to be installed a few years hence.

After passing these racks the water is controlled in its passage

to the turbines by structural-steel gates. Eight of these for the generating units are built of 6-inch I-beams, and are covered with ⅜-inch steel plate on the outer side. On the inner side they have bronze running strips at the sides and opposite the supporting

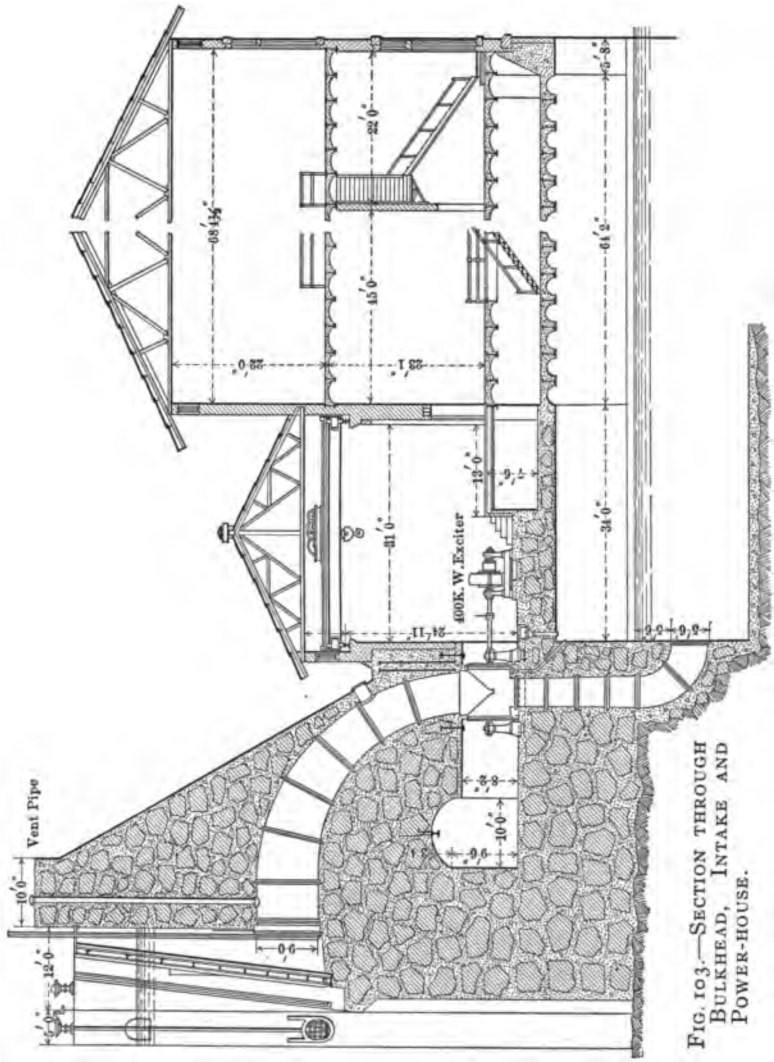



FIG. 103.—SECTION THROUGH BULKHEAD, INTAKE AND POWER-HOUSE.

beams in the gate frame, while machined-steel bearing plates at top and bottom insure tightness when the gates are closed. Each of these gates is provided with two 9 × 14-inch filling gates for reducing the pressure before raising, these being hand-operated from the top of the bulkhead. The gates are suspended upon steel stems, each built up of an 8-inch, 18-pound I-beam, and a 9-inch, 20-pound channel, and to the latter is secured the pinion rack engaging with the gate hoist.

The gates are operated by a multiple spur and worm gear off a shaft actuated by a motor from a point in its middle. The motor is stationed in a small house on top of the bulkhead, the leads for it being carried in vitrified conduit to a switch box in the tunnel and thence to the switchboard. Speaking-tubes are carried from this house and also from various points in the transformer-house to the operator's desk in the power-house. On account of the great initial torque required, a direct-current compound-wound motor with a weak shunt field, operating from the exciter circuit at 250 volts, was selected for this service. This is practicable since the exciter plant is of a capacity largely in excess of that required for the mere excitation of the generators. By the use of pin clutches it is possible to operate any or all gates at one time. The clutches must, of course, be thrown in while the shaft is at rest. Provision has also been made for operating any of the gates by hand.

The two gates for the exciter intakes are similar to those just described, except that they are framed out of 4-inch I-beams, the stems being composed of a 6-inch 12½ pound I-beam and a 9-inch 13¼-pound channel, and but one 9 × 12-inch filling-gate is provided. They are raised by hand-operated mechanism. All these gates slide in heavy frames built of structural-steel shapes anchored into the masonry of the bulkhead wall. Directly behind the gate frames, but not rigidly attached to them, commence the intake flumes or feeder pipes for the water-wheels. These are made of ⅜-inch boiler plate stiffened by 6 × 3½ × ⅜-inch angles riveted around it. These flumes taper down from the head-gates, where they are 16 feet wide

by $18\frac{1}{2}$ feet high with semicircular ends, to 16 feet in diameter at the mouthpiece of the turbine case.

*Turbines.*—There are ten units, each consisting of a pair of horizontal twin turbines with top inlet and centre discharge. Eight of these are required to furnish 5,200 H.P. at 225 r.p.m. under a head of 72 feet.

Of these units two are a pair of 48-inch wheels enclosed in a cast-iron wheel case mounted in a turbine case of 7-16-inch boiler plate riveted to cast-iron heads. The latter are stiffened against shocks by four $2\frac{1}{2}$-inch Norway-iron rods extending from the front to the rear head.

In the feeder pipe and over the centre of the turbine is a man-hole, just inside which is an eye-bolt for the suspension of blocks for handling turbine parts. Pressure and air vent pipes 12 inches in diameter run up through the bulkhead.

The draft tubes are 8 feet 10 inches in diameter at the wheel case, being flared at the bottom to a width of 18 feet, the ends being semicircular and of 4 feet 5 inches radius. The top of the mouth is sprung to form an arch 2 inches high to prevent any possible collapse of the metal away from the masonry. These tubes are fabricated from 7-16-inch plate and are stiffened in the same manner as the intake flumes.

The plates of the upper 12 feet of the draft tube from the saddle down are butt-jointed and strap-covered on the outside with countersunk rivets on the inside. Below these plates the joints are telescopic, with the lap in the direction of the flow of water. In the heads of the turbine case are removable crown plates of such size as to permit removal of any part of the work inside the flumes.

Should it become necessary, the turbine cases may be drained by valves operated from the power-house. Check valves, for removal of any water seeping into the power-house, are provided before each unit in a sump, which extends the entire length and in front of all the wheel cases.

Vacuum gauges are provided for all draft tubes. The draft head in these wheels is 22 feet, and the draft tubes are submerged

5 feet, which depth was deemed necessary to permit drawing off the pond on the lower development.

The runner of each wheel is of bronze and mounted on a shaft 30½ feet long made of forged nickel-steel; it is 9, 10, and 11 inches in diameter, with a flange coupling keyed to it for connection to its generator. This shaft is supported on the outside of the turbine case by ring-oiling, ball-and-socket bearings, the one in the power-house being made to harmonize in appearance with the bearings of the generators.

A special feature of this plant is the construction of a tunnel extending the length of the power-house through the bulkhead and just back of the turbine cases. By this method of construction the usual outboard water-bearing is replaced by an oil bearing which may be inspected at will, and the removal of water-wheel parts is also greatly facilitated. This tunnel is 10 feet in width and has a segmental arch top, in which is anchored an I-beam trolley for carrying material to and from the power-house, into which the tunnel opens. Ventilation is here provided by three, 12-inch air flues to the top of the bulkhead. The water-wheel shaft extends into this tunnel through a cast-iron head similar to that in the power-house.

The outer bearings are ring-oiling ball-and-socket bearings of the propeller type. The pedestal boxes are rigidly connected to the head, being designed to take up the end thrust of the water-wheels. The flow of water to these wheels is regulated by cylinder gates. All racks and pinions for the gatework are placed on the outside of the turbine case. Hand regulation is provided for these units separate from that of the governors.

The guaranteed efficiency of each of these units is determined by a curve passing through the following points:

| | | | | | |
|---|---|---|---|---|---|
| Discharge | Full | $\frac{7}{8}$ | $\frac{3}{4}$ | $\frac{5}{8}$ | $\frac{1}{2}$ |
| Efficiency per cent | 81 | 82 | 81 | 74 | 68 |

Six of the larger units are set in a turbine case of 7-16-inch plate, 15 feet in diameter and 19 feet long. In this case the cast-iron heads are stayed across the wheel case. The feeder pipe is 18½ × 16

feet at the intake gates, and tapers to 15 feet in diameter at the mouth piece of the turbine case.

The draft tubes are 11 feet in diameter at the base of the wheel case, and flare to 18 feet 3 inches by 11 feet 2 inches at the lower end. Two of these units are provided with bronze runners 53 inches in diameter, and four have runners of special cast iron, the latter being guaranteed against failure or undue wear for a period of five years. The gates are of the register type, being nearly balanced, with, however, a tendency to close.

The shaft is of forged steel 9, 11, and 13 inches in diameter, and has a flange coupling forged to its end for the generator connection. The guaranteed efficiency curve passes through the following points:

| | | | | | | |
|---|---|---|---|---|---|---|
| Discharge........................ | Full | $\frac{7}{8}$ | $\frac{3}{4}$ | $\frac{5}{8}$ | $\frac{1}{2}$ | $\frac{1}{4}$ |
| Efficiency per cent............ ... | 80 | 81 | 82 | 80 | 78 | 60 |

The two exciter units are similarly built. These were required to furnish 700 H.P. at 450 r.p.m. under 72 feet head.

At the intake the feeder pipes are 9 feet high with semicircular ends of 3-foot radius, and taper to a diameter of 6 feet at the mouth-piece of the case. These pipes are equipped with manholes and 8-inch vent pipes. Runners are 24½ inches in diameter, the shaft 5½ inches in diameter, and the draft head is 21 feet 2 inches. The draft tubes are 5 feet 6 inches in diameter at the case and flare to a width of 9 feet 10 inches with semicircular ends of 2 feet 9 inches radius.

For facility in erection, the water-wheels were mounted on a long, heavy structure of I-beams to span the openings left in the masonry for the draft tubes extending from the arches of power-house substructure to the masonry built up outside the draft-tube clearances. It was proposed setting these with the cradles in place, rigidly suspending from them the draft tubes, and then filling in around them with concrete. However, owing to delayed deliveries of the cradles, the draft tubes were loosely suspended from temporary beams braced to position and concreted in, the connection with the cradle fitting very well.

Regulation of this plant is effected by Lombard governors. The generators are governed in pairs, and for each pair a type N governor is provided, while both exciters are controlled by one type P governor. There are provided for this installation four 4 × 6-inch triplex pumps operated by a belt from the water-wheel shafts. All pressure and vacuum tanks are placed in the bearing tunnel and the entire system is interconnected. The type N governors developing 31,000 foot-pounds are guaranteed to completely open or close the water-wheel gates in 1½ sec., while the type P governor will close exciter gates in 4 sec., developing 6,700 foot-pounds. The larger governors are electrically controlled from the switchboard.

*Power-house.*—The generator turbines discharge into the tail-race between piers, which, being spanned by full centred arches, form the substructure of the power-house. These piers are 5 feet in width and 25 feet between centres, except where both exciter turbines discharge into the same bay, the piers forming this one being 30 feet between centres and bridged by an elliptical arch, giving the same rise as the full-centred arches. All piers and also the facing on exposed parts of the substructure were built out of very finely finished dimension stone, which was quarried out of locks built in the early part of the last century by the State Government in an attempt at making the river navigable past the falls and shoals. By this means and by paving the bottom with concrete, these tail flumes were made quite smooth and present but little impediment to a rapid discharge of spent water. The piers for the three central bays are carried in a like manner down-stream from the power-house to form the substructure for the transformer-house, but here the span between piers is not bridged by an arch, except just at the lower end, where these arches carry the outside wall and were used largely for the sake of maintaining a uniformity in the external appearance of the structure.

The power-house is 250 feet long and 37 feet wide; the transformer-house extending from this is practically, a three-storied building, 71 feet in width and 85 feet long. These buildings,

of fireproof construction, are faced on the outside with red pressed brick and on the inside with a gray sandlime brick, the body of which is granite dust. Weepers were built just back of the brick walls on the bulkhead side of the power-house, drainage from these leading to the sump in the power-house. The roof covering consists of tile resting directly on steel purlins supported by steel trusses. These tiles lay up 24 × 48 inches, and are built of concrete reinforced by expanded metal and made interlocking. They have a water-proofing burned into the exposed surface. The roof of the transformer-house was designed with a wide overhang for the protection of the line openings. Proper ventilation was provided for by the use of very large windows with casement side sash, which may be widely opened. Windows were also placed above the crane track on the upstream side of the house. These windows are hinged on top, the entire gang being operated from two power sash-lifting devices at opposite ends of the power-house. By this means it is possible to close them readily in case of sudden shower when rain might blow in on the electrical machinery. Two 20-inch ventilators were placed in the roof over each bay, and a 48-inch slat ventilator was built into each end of the house. In both ends of the house are placed steel rolling doors with a clear opening of 16 × 11½ feet.

A conduit for the accommodation of wires and pipe extends along the downstream side of the power-house, the top forming a platform 3 feet 9 inches above the floor line. This platform widens on a circular arch in the centre of the house, opposite the exciter, forming a dais for the mounting of switchboard and instrument posts. A hand-operated travelling crane runs from one end to the other of the power-house. This has a capacity of 25 tons, and is equipped with a drum on which is wound the plough-steel hoisting rope. The girders are built of reinforced I-beams, and on the lower flange of one of these operates a 5-ton auxiliary trolley with triplex block. In the tunnel a 5-ton trolley is suspended from the crown of the arch on an I-beam track for the handling of wheel and bearing parts.

The transformer-house, as already stated, is a two-storied structure, the conduit floor or basement of which is practically on a level with the bottom of the cable conduit in the power-house. The skeleton of this floor consists of I-beams spanning the opening between piers, the space between these beams being spanned by concrete arches with a concrete covering protecting the lower flanges of the beams. The piers were carried full width through this floor. The floors of the first and second floor are similarly constructed except that curved corrugated steel sheets were supported on the lower flanges of the I-beams, and on these was placed the concrete. The first floor is on a level with the switchboard platform. It is divided into rooms for housing transformers over both side bays and extending the full length of the house, while that portion lying above the piers of the central bay forms a room for low-tension switching apparatus. Immediately back of the switch-room and overlooking the tail-race is an office for the operators. From the power-house, entrance is gained to those rooms in which the transformers are placed through arches protected by rolling steel fire doors with fusible links. A similar door divides these rooms into two separate compartments, so that any one bank of transformers will be automatically isolated from the others in case of fire. The second floor has no partitions in it whatever, forming thus a room of such size as to contain all the high-tension apparatus with a generous allowance for clearance between leads. All apparatus is taken up through trap doors located above the tracks for the transformer transfer carriage, thus making their handling a simple matter. A 36-inch ventilator in the roof will insure against excessive temperatures in this room.

## THE HYDRO-ELECTRIC DEVELOPMENT AT TRENTON FALLS, N. Y.

*Abstracted from The Electrical World of May 19, 1906.*

THE waters of the Canada Lakes in the Adirondacks of New York State find their way to the Mohawk River through two streams

known as the East and West Canada Creeks. The former empties into the Mohawk at East Creek and the latter at Herkimer. The West Canada Creek is the larger, and near the village of Trenton Falls it has a descent of nearly 300 feet in less than a mile. It is at this place that the 8,000 H.P. hydro-electric station of the Utica Gas and Electric Company is located.

*The Dam.*—The dam is a concrete structure of the gravity type, 300 feet long and 60 feet high, built across the Creek on the arc of a circle having a radius of 800 feet, at a point about three-quarters of a mile distant from the power-house.

Eight 60-inch cast-iron pipes are built into the dam near the bottom, two of which supply the pipe line feeding the turbines now installed, two for the supply of a second pipe line when the power-house is extended, and four to assist the waste weirs in carrying off the excess water in times of extreme floods. All of the 60-inch pipes are equipped with cast-iron sluice-gates having bronze guides and are operated from the top of the dam.

The flood-water weirs above-mentioned are two in number, one being built at right angles to the dam and close by it on a rock shelf on the east bank of the stream, the other forming a part of the dam proper. The first weir or spillway mentioned is 160 feet long, the crest being 9 feet lower than the top of the coping on the dam. The second weir is 100 feet long and its crest is two feet higher than the crest of the former.

By this construction, the waste of flood water in the reservoir will flow over the spillway first mentioned through a rock cut around the dam to the creek below until the water flowing over it is two feet in depth, when the spillway on the dam will come into action and both weirs will then carry the waste water. The first weir mentioned can be provided with flash-boards, so that the level of the water in the reservoir can be raised two feet during the dry season.

Both the dam and the weir on the dam are capped with heavy stone coping securely held by dowel pins, while substantial stone wing walls are constructed on the downstream face of the dam

to confine the flood water within the limits of the spillway and thereby protect the face of the dam from injury due to debris, etc., in time of floods.

*The Pipe Line.*—The conduit which conveys the water from

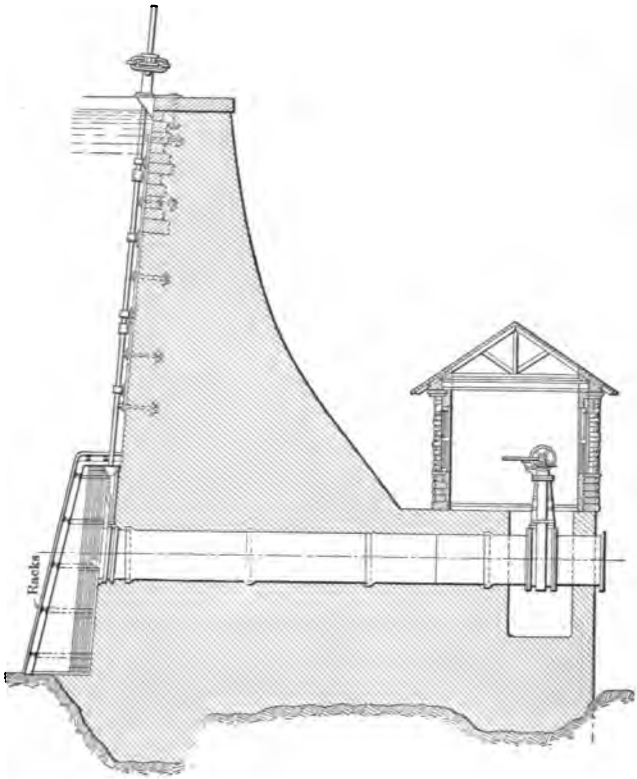



FIG. 104.—SECTION THROUGH BULKHEAD.

the reservoir to the turbines in the power-house is 84 inches in diameter and about 3,700 feet long. It is connected to the two westerly 60-inch pipes in the dam by means of a 60 × 60 × 84-inch cast-iron Y piece and two 60-inch gate valves enclosed in a gate-house, the latter being used to control the flow of water in the pipe line.

The long pipe is composed of wooden-stave and steel-plate pipe, the major portion of its length being constructed of Texas pine staves securely held in position by round-iron bands, and joined to the steel pipe 2,900 feet from the dam.

Twenty wooden staves, each $2\frac{3}{8}$ inches thick, sawed on radial lines, are used in forming the circumference of the 84-inch diameter circle, the lumber being the best of its kind that could be obtained.

The steel pipe, which is about 800 feet long, is built of plate varying from $\frac{3}{8}$ to $\frac{5}{8}$ inch in thickness, and thoroughly coated inside and out at the mill with hot asphalt pitch. All connections of plate are made with lapped joints, the circumferential seams being single riveted, while the longitudinal seams are double-riveted. All pipe constructed of $\frac{3}{8}$-inch material is stiffened by means of angle irons.

The wooden-stave pipe is built on a light descending grade, and it winds in and out along the west bank of the creek throughout its entire length. After its junction with the steel pipe, the grade becomes much greater and the pipe continues in a straight line for several hundred feet to a standpipe 84 inches in diameter and about 200 feet in height, which is built into the supply conduit to relieve any pressure in the line caused by extreme load conditions. This standpipe, which is covered with shingled casing

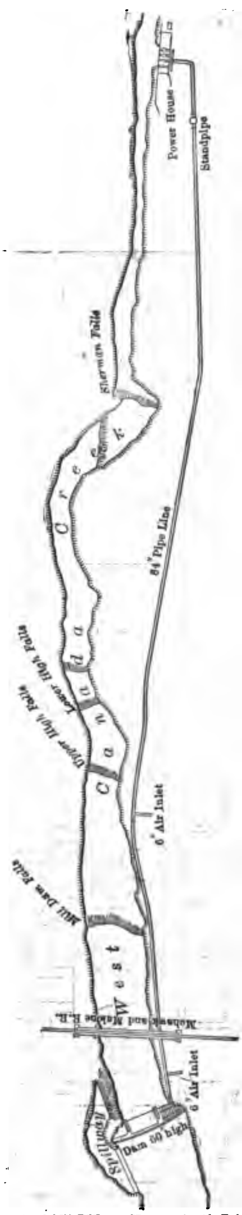



FIG. 105.—MAP OF TRENTON FALLS DEVELOPMENT.

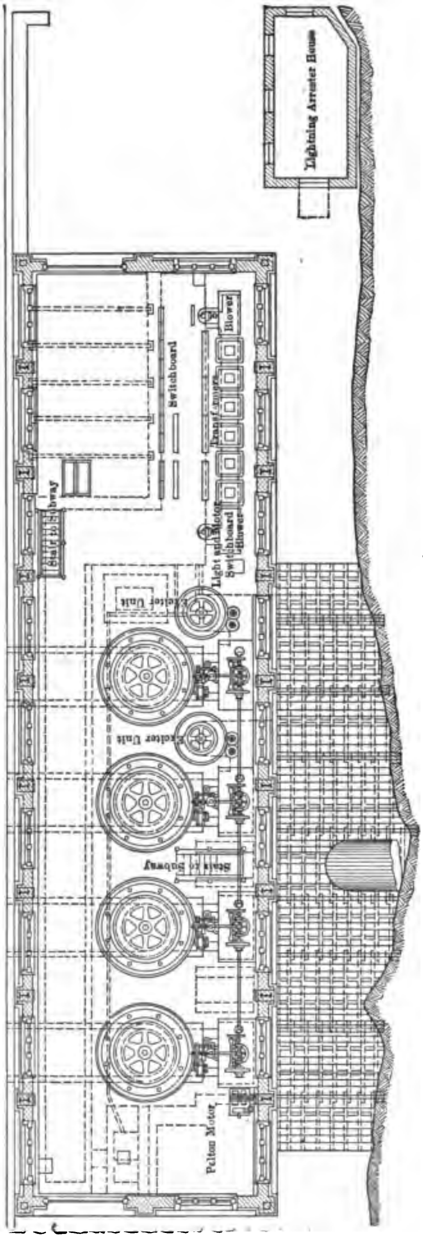


FIG. 106.—PLAN OF POWER-HOUSE.

having a well-shaped cupola at the top, is 20 feet higher than the dam.

Just after passing the standpipe, the penstock descends along the cliff at a sharp angle to a reservoir near the power-house, 125 feet below the top of the bank. The reservoir is anchored on concrete foundations just outside the west wall of the power-house. It is provided with four 48-inch outlets, each of which delivers water to a turbine wheel under a head of 266 feet. The flow of water to each turbine is controlled by a 48-inch gate valve, the arrangement being such that any or all valves can be operated simultaneously by hand, or by power furnished by a Pelton water-wheel.

The penstocks to the turbines, the pipe line, and receiver are all equipped with valves to assist in relieving any excess pressure which might come on them, and the main pipe line is provided with a

number of air inlet pipes to allow for the escape or intake of air when the line is being filled or emptied.

*Hydraulic and Electrical Machinery.*—The turbine units are six in number, four driving the large generators and two furnishing power to the exciter dynamos. The former units are of a Fourneyron or outflow type, the water from the wheel runners discharging into a draft tube. They have vertical shafts, hydraulically operated governors, and are direct-connected to the generators. They have a rated capacity of 2,000 H.P. at full gate opening when working under 264-feet head.

The exciter turbines, which are of the Girard type, develop 100 H.P. at full gate opening when operating under the above-mentioned head. They also have vertical shafts, direct-connected to the dynamos, the speed regulation being under hand control. The supply pipes of each exciter turbine, which are 12 inches in diameter, are attached to the penstock of the units nearest them, the flow of water being controlled by a gate valve operated by hand power only.

The main generators are alternators of the internal revolving-field type, producing three-phase current at 2,300 volts, and 60 cycles when the field is rotating at 300 r.p.m. The exciter dynamos are 125-volt machines and revolve normally at 750 r.p.m.

The switchboard is of the usual type, having a marble panel for each of the large units and one panel for the two exciter units. It also has separate high- and low-tension feeder panels. The potential of the current leaving the low-tension feeder panel, is stepped up to 23,000 volts by air-cooled transformers, from which the current passes to the high-tension feeder panel, thence out of the building through the lightning arresters located in a separate building near the power-house, and finally along the transmission line to the substation in Utica, twelve miles away.

*The Power-house.*—The power-house, which is situated in a rocky gorge slightly more than 100 feet in width and varying from 125 to 150 feet in depth, is a well-appointed building in all respects. It is 32 feet wide and 128 feet long inside, and around the skeleton

steel framework are built walls of Gouverneur marble, while the interior is trimmed with white and brown enamel brick to the window sills, and above this point with cream pressed brick to the roof. It is furnished with a 10-ton travelling crane for convenience in

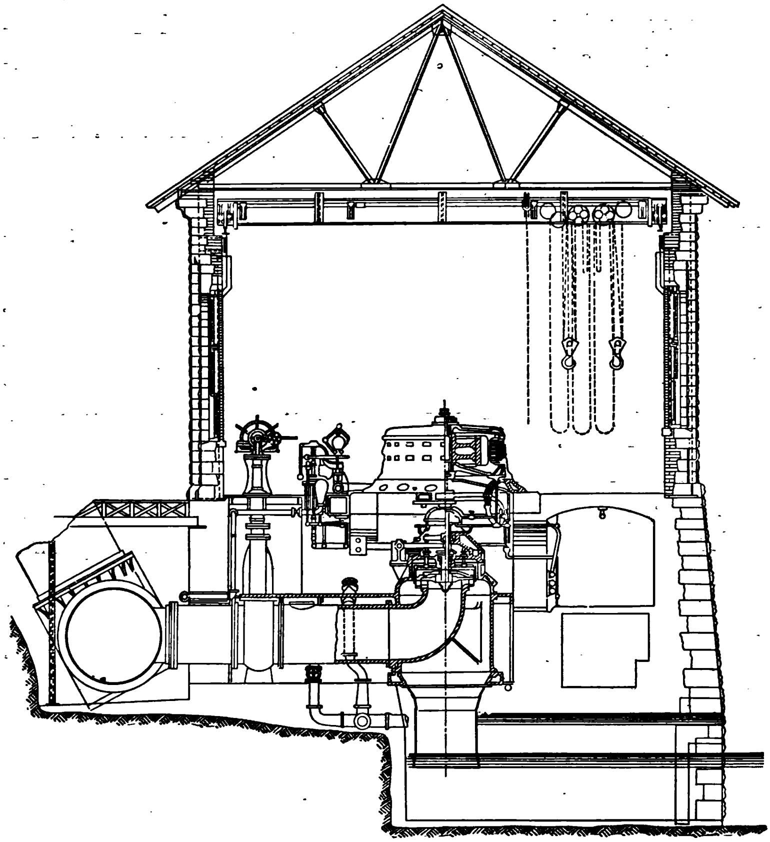


FIG. 107.—CROSS-SECTION OF POWER-HOUSE.

handling any part of the hydraulic or electrical machinery. A view of the interior of the power-house is shown. The turbines are all below the granolithic floor, in separate wheel pits.

One important feature of the plant is there is no trouble from

anchor ice, due to two precautions which were taken when the dam was built. First, the pipe line enters the dam 40 feet below the surface of the water, and anchor ice does not sink to the level of the pipes. Second, the crest of the spillway which carries surplus water around the ends of the dam is 2 feet lower than the spillway on the dam, and a strong current is thus established which carries the anchor ice around the end of the dam, and far away from the pipe-line intake, which is on the opposite side of the stream.

At Utica there are two modern direct-connected steam stations, with a total capacity of 8,000 H.P., which can be started at once in case of interruption of the transmission lines from Trenton Falls. The last steam unit, which was installed last fall, is a 3,000 H.P. steam turbine, and generator of same capacity.

*Extensions.*—The company proposes to add 8,000 H.P. to its Trenton Falls station, bringing its capacity up to 16,000 H.P., and also develop its water power at Prospect, about one mile above Trenton Falls dam. At Prospect a plant having a capacity of 6,500 H.P. will be built, and at Enos on the Black River, nine miles from Prospect, the company will build a station having a capacity of 3,000 H.P.; thus the company will possess a grand total of 25,500 H.P. in hydro-electric generators.

## THE HYDRO-ELECTRIC PLANT OF THE McCALL FERRY POWER COMPANY.

*Abstracted from The Engineering Record of September 21, 1907.*

There is now under construction at McCall Ferry, Pa., a hydro-electric plant having many unusual features in both design and methods of construction. It is on the Susquehanna River about 25 miles from Chesapeake Bay.

*Hydraulic Conditions.*—The Susquehanna River has a drainage area of 27,400 square miles, the larger part lying in Pennsylvania. Its watershed includes the steep slopes of the Allegheny Mountains, which cause sudden rises of rather frequent occurrence.

The river occupies a deep valley, and for 125 miles above its mouth has an average slope of 3½ feet per mile, the fall at McCall Ferry being 8 feet per mile. The conditions on which the design of the plant is based have been studied at Harrisburg since 1890 and at McCall Ferry since 1902. The records thus obtained show that with the adopted head of about 55 feet the flow of the river assisted by an adequate storage capacity can be depended upon for the continuous development of 100,000 H.P. The storage will be secured by a lake 6 miles long and 4,000 feet wide, formed by the dam. The discharge necessary to develop the normal rating of the plant on a 12-hour load is 10,000 cubic feet per second, corresponding to an average run-off on the catchment area of 0.47 cubic foot per second per square mile, the drainage area above McCall Ferry being 26,766 square miles. The discharge as peak load will be 27,000 cubic feet per second. The flood flow considered in making the plans was about 671,000 cubic feet per second; the record of the highest flood, that of June, 1889, corresponding to an average run-off on the drainage area of about 25 cubic feet per second per square mile. The floods come with great rapidity, the flow in the river frequently jumping from 30,000 to 100,000 cubic feet per second or over. The necessity of providing carefully for these conditions is further emphasized by the large amount of ice carried toward the end of the winter, much of it in large, thick cakes.

*Dam.*—The plant and dam are built at a point where the river is about 2,600 feet wide and divided into two channels by Fry Island. The east or Lancaster channel is about 900 feet wide, and the west or York channel about 1,200 feet, and the island about 500 feet. The stream is only 400 feet wide a short distance above the dam, but the depth and swiftness of the current forbade construction there. The present site offers a ready means of handling the flow during construction by reason of the two channels. Above and below McCall Ferry the river is dotted with small islands and crossed by ledges, on one of which the dam rests. The water a short distance above and below it is very deep. Another such

ledge crosses the river at Cully's Falls, and a channel had to be cut through it for the tail-race. The rock, though hard, is considerably eroded and fissured.

On account of the floods, the dam has been constructed as a spillway throughout its entire length of 2,350 feet. The dam extends only 600 feet across the Lancaster channel, the remainder of the channel being spanned by the power-house. Its crest is 45 to 50 feet above the average summer water level. The section

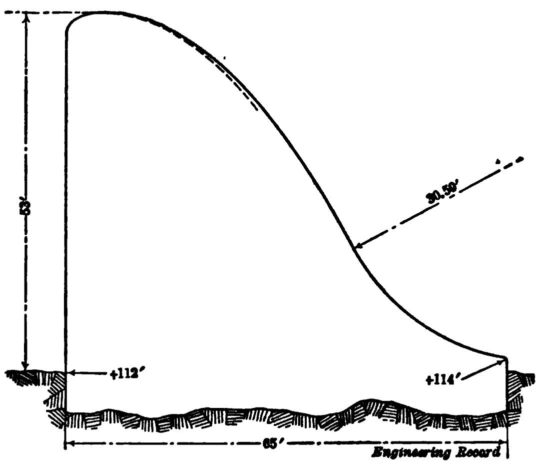



FIG. 108.—SECTION OF DAM.

has been calculated for a head of 17½ feet, above the crest corresponding to a flow of 304.7 cubic feet per second per linear foot of the dam, a quantity equal to the maximum recorded flow of the river. The section was calculated on the assumption that the weight of the masonry was 135 pounds per cubic foot, and the weight of the falling water over the dam and the pressure of the water on the apron were neglected. The base of the dam is uniformly 65 feet wide, below a point 51 feet down from the crest. Where the dam crosses the island, the ledge rises to within 41 feet of the crest, necessitating a change in the section, which was made by retaining for the lower part of the apron the same curve as was

used elsewhere, the only difference in the two sections being in the length of this lower curve of the apron. The front face is vertical.

The dam is 1:3:5 Portland cement concrete with pudding stones up to 1 cubic yard in size. The sand is coarse and very clean, secured from a bank at Charlestown, Md. The stone is a very hard trap, weighing 193 pounds per cubic foot, used without screening, and contains pieces running up to 7 inches in length. The pudding stones are of the same rock, which is obtained at a quarry operated by the company at Conowingo, Md. These stones, forming 20 per cent of the total yardage, are placed not closer together than 8 inches and 2 feet back from the surface of the concrete. The amount of material in the dam is 174,000 cubic yards.

*Power-house.*—The power-house occupies the eastern part of the east or Lancaster channel, and stands at an angle of forty-two degrees with the face of the main dam. In front of it is a forebay, where the racks and screens are located, and the entrances to the chutes for disposing of any ice which gets into the enclosure. The conduits leading to the turbines start immediately back of the inclined racks. They are built entirely of concrete, no steel being used either for reinforcing or for the intakes or draft tubes. The ten turbines are beneath the power-house floor, five on each side of the two exciters in the centre of the building. South of the power-house is the transformer-house, carried by arches spanning the draft-tube outlets in the tail-race.

The front wall of the forebay is carried on 11 arches, the crowns of which are 6 feet below the crest of the dam, and 1 foot below the low-water level, so that they will always be submerged. Back of the arches and carried on inclined piers are the screens, and back of them are the gates closing the intakes to the turbines. The screens are built in panels 10 feet wide and 11 feet high, four tiers to a unit. They have frames of 10-inch channels, supporting the screen-bars, which are 7-16 × 4½ inches, with 2-inch spaces between them. Instead of using gas-pipe separators, as is generally done, the bars are kept apart by plates ⅜ inch thick, which

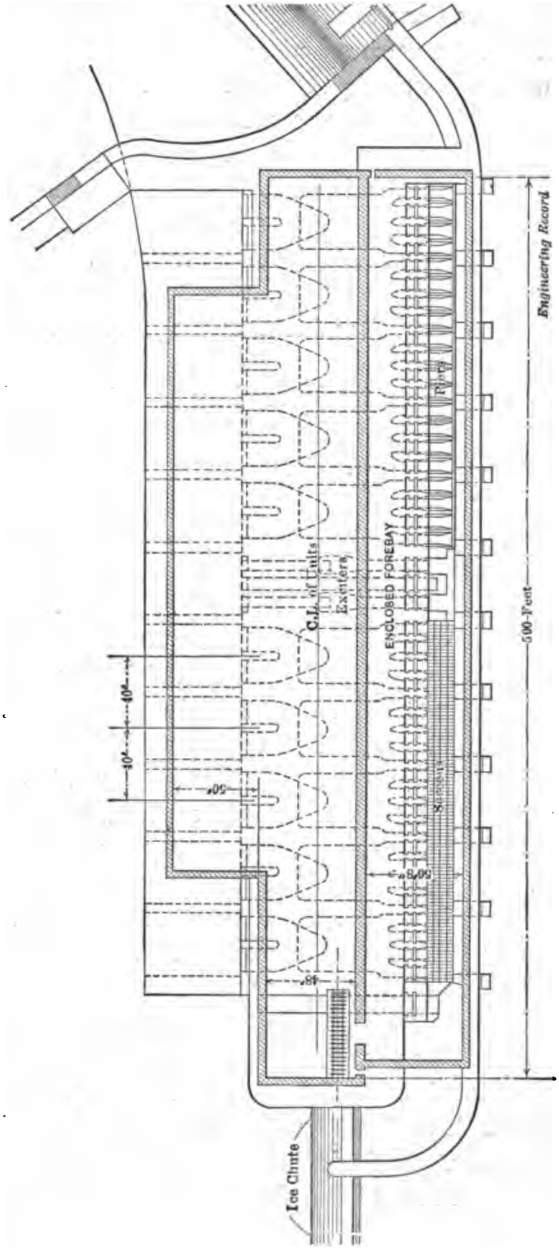



FIG. 109.—PLAN OF POWER-HOUSE.

have notches cut in them of the thickness of the bars. The strips of metal between the notches are bent over the rods on which the bars are hung, thus holding the latter apart. The frames slide in cast-iron seats bolted to the noses of the inclined piers. This arrangement allows the screens to be withdrawn for repairs and cleaning by merely catching them with a line from the crane, and pulling them out. Within the forebay are two chutes for disposing of any ice that may get by the exterior ice protection. One of these chutes 6 feet square is located between the two exciters at the centre of the power-house, and the other measuring 8 × 10 feet is at the east end of the forebay.

The gates closing the intake conduits are 16 feet high and 6 feet wide, and are raised and lowered by the large travelling crane in the screen and gate-room. An auxiliary gate, also lowered and raised by the crane, is cut into the main gate, and can be opened so as to equalize the pressure in the forebay and the intake conduits.

The intake conduits for the main units start in three openings separated by piers each 6 feet wide and 16 feet high. Eight feet back from the gates these three passages merge into one which is 15 feet wide, and for a short distance 13 feet high, expanding where the conduit forms the turbine chamber, to a height of 33 feet. There are two draft tubes, one leading from each wheel of the unit. These draft tubes join about 20 feet from the unit, but are here divided by a vertical wall, the discharge outlet into the tail-race of each unit being composed of two passages, each 13 feet wide and 15 feet high. This arrangement of the draft tubes, since they are constructed of solid concrete, necessitated very complicated form-work, especially since it was necessary to have easily curving surfaces which would offer little or no resistance to the flow of water. The exciters are located in the centre of the power-house with five main units on each side of them. The intake conduits and draft tubes for them are 6 feet square in section.

Each turbine is set in the concrete chamber without the usual steel or iron casing. Each chamber can be closed independently of all the others, and after being closed by the gates in front of the

intake conduits and the stop-logs at the ends of the draft tubes, can be drained through outlets leading to pumps installed for that purpose.

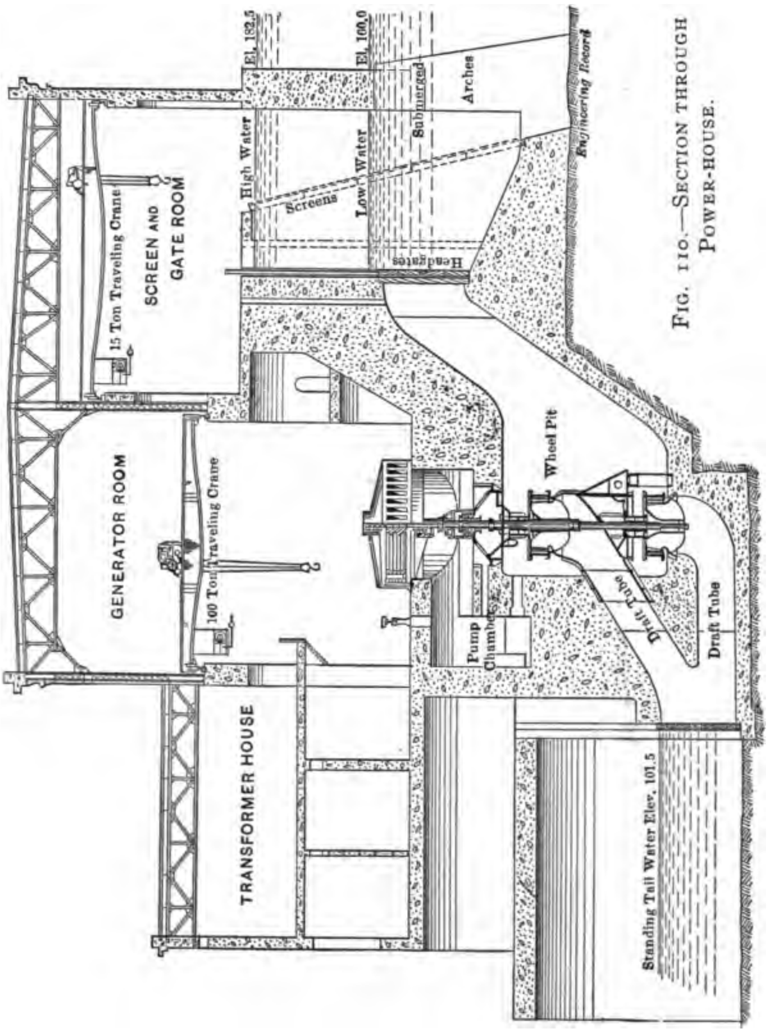



FIG. 110.—SECTION THROUGH POWER-HOUSE.

Below the power-house floor runs a chamber parallel to the length of the power-house in which will be installed the pumps for

draining the wheel chambers and the turbine-driven oil pumps for supplying the thrust bearings with oil.

The turbines are of the vertical shaft, inward and downward flow, Francis type. There are 10 main units each capable of developing 13,500 H.P. under a head of 53 feet with the gates open 80 per cent at 94 r.p.m. Each turbine when run at its rated load will take about 2,700 cubic feet of water per second. Each turbine has two separate wheels mounted on the same shaft, the latter being of forged steel, 20 inches in diameter. The upper wheel discharges through a steel casing leading to the draft tube while the lower wheel is set immediately over the draft-tube pit, and discharges into it without the medium of a casing. The wheels are about 10 feet in diameter.

The weight of all the moving parts of both generator and turbine is carried on a thrust bearing which is supplied with oil from pumps driven by small turbines. Separating the oil pumps in this manner from the main units allows the oil in the thrust bearing to be put under pressure before the unit is started. The thrust bearing, which carries a total weight of 335,000 pounds, is supported by a lens-shaped casting set into the concrete. The exciters have a capacity of 1,000 H.P. and are of the same general type as the main units.

*Ice Protection.*—The large amount of ice which has to be disposed of and its long continuance each winter have necessitated special precautions for protecting the plant and turbines. It is aimed to keep the entire enclosed forebay free from ice, and to accomplish this an outer forebay is provided and separated from the main river by a series of submerged arches and timber cribs, which form racks holding in place floating booms. This ice protection is 630 feet long, and stretches from the point where the main dam and the power-house join to a ramp 300 feet long built out from the shore. The concrete ice protection consists of 3 submerged arches each having a span of 68 feet with 8-feet piers between them. The crowns of the arches are 2 feet below the estimated low-water elevation so that the arches are always submerged;

the ice and floating débris being thus stopped and floated toward the dam, where a special runway for this purpose has been constructed between the main dam and the power-house. The top of this concrete structure rises to a height of 22 feet above the crest of the dam and 4½ feet above the high-water elevation. The top is 6 feet wide and the back face has a batter of 4 inches to the foot, the piers at rock foundation being 30 feet. long. The space between the concrete structure and the ramp is occupied by four timber, rock-filled cribs, spaced 104 feet apart and supporting floating booms. These cribs are 24 feet wide and 16 feet long on top, the length increasing with the depth, being 64 feet at the foundation. The floating stop-logs between the cribs are made of three layers of six 10 × 12-inch timbers each. They are bolted together with spaces between them so as to make the boom 7 feet 8 inches wide and 3 feet thick. The boom slides in recesses in the timber cribs, rising and falling with the stage of the water above the dam. The direction of the ice protection is parallel to the flow of the river so that the flow will assist in carrying the ice and débris toward the main dam and over the runway.

In addition to this ice protection, a spillway has been provided between the power-house and the shore for disposing of any ice which forms in the forebay or finds its way into it. This spillway 40 feet wide has the same elevation as the crest of the main dam. Separating it from the power-house and protecting the latter from the ice passing to the spillway is a wall 8 feet thick reaching above the high-water elevation. This spillway cuts off the power-house from the shore, and access between them is had by a bridge 5 feet wide, and by a tunnel 14 feet wide and 16 feet high running through it. The tunnel is laid with a standard-gauge track which extends 55 feet inside the power-house, allowing the machinery to be handled directly from the cars by the power-house cranes.

*Tail-race.*—The tail-race, 3,000 feet long, is nothing more than the former bed of the Lancaster channel, lying between the east bank of the river and the chain of islands south of Fry Island. This channel presents a very curious formation. The bed is of

solid gneiss, with benches on either side submerged at the original condition of the river from 7 to 10 feet, and having between them a channel about 100 feet wide and from 80 to 90 feet deep, with vertical walls. This unusual depth continues until near the point where the tail-race flows into the main channel of the river. A ledge of rock is here encountered through which a channel 1,000 feet long and varying in width from 150 to 300 feet is blasted. In order to prevent the river from flooding the tail-race by flowing through the openings between the islands which separate the two channels, rock-filled timber cribs are thrown across these openings, and carried above the highest level which the water in the channel can reach. At the point where the rock ledge obstructs the channel near the end of the tail-race a concrete weir is built, with its crest at the same elevation as the top of the draft-tube outlets, so as to preserve a water seal for the turbines.

In order to prevent a large volume of the water which comes over the dam from finding its way at once into the tail-race, and thus raising the level of the latter, a deflecting dam 576 feet long starts at the junction of the main dam and the power-house, just opposite the beginning on the upstream side of the ice protection, and runs over to Piney Island, which lies south of Fry Island. This dam is built of solid concrete, using pudding stones and the proportions which were adopted for the main dam. Its crest is at the same level as the power-house floor, 14 feet below the crest of the main spillway. With this dam, and the cribwork between the islands below the plant, the water coming over the main dam, is confined entirely to the western or York channel, allowing the Lancaster channel to be used for the tail-race. The low-water level in the latter is about 15 feet below the water level in the spillway channel immediately below the dam.

*Construction.*—Construction was first started across the Lancaster channel, which carried the greater volume of water and in which the power-house is located. On account of the rapid rise of the river, and the large discharge during high water, the problem of constructing the dam was a serious one. To have provided

against the maximum flood during construction would have involved great expense, while any less provision meant the occasional stoppage of the work, and the probable loss or damage of the construction equipment and the partially completed work. After a thorough study of all the conditions it was decided to construct a cofferdam sufficiently high to prevent being overtopped by a flood less than 60,000 cubic feet per second. Daily reports regarding the weather conditions on the watershed were received from the weather bureau at Harrisburg, and when a flood above 60,000 sec. feet was on the way preparations were made to meet it. Such a case occurred on March 15, 1907, when a flood of 320,000 cubic feet per second swept over the work. Warning had been received and everything movable in the path of the water was moved to a place of safety, and work carried on without interruption until within an hour of the arrival of the flood, when the remaining equipment was run to cover. The flood did no damage to the partially completed dam and power-house, but carried off four standard-gauge tracks laid with 60 pound rail which were on the construction bridge below the dam.

*Cofferdam.*—The first step in the actual work of harnessing the river consisted in building the cofferdam, a rock-filled timber structure 1,000 feet long and about 300 feet up the river from the site of the dam. Soundings had been made across the channel at the places where the cribs were to rest, and, where these did not give a satisfactory description of the bottom, divers were sent down to get more accurate information. The bottoms of the cribs were then framed on shore to fit the rock foundation on which they were to rest, and, after having a few courses of timber built upon them, were launched, towed into position, and held there by cables anchored on shore. They were then built up in the usual manner, the timbers, which were 8 × 10 inches, being drift-bolted together with $\frac{7}{8}$-inch drift-bolts, 30 inches long. The materials were conveyed to the cribs by means of a cableway with a span of 1,200 feet over the site of the cofferdam. In addition to this means of conveyance, a standard-gauge track was carried out and

extended over each separate crib as soon as completed, and on it was run a travelling stiff-leg derrick. Rock was placed in the cribs to sink them as the timber work was carried up. The cribs were 16 feet wide and varied in length, in multiples of 8 feet from 24 to 40 feet, being built in bays 8 feet square. The deepest crib was about 30 feet below the original low-water level.

The openings between the cribs were closed with stop-logs, and in front of them were placed two rows of 2-inch timber sheeting breaking joints. The careful placing of this sheeting is largely responsible for the remarkable tightness of the cofferdam. The separate planks were driven to the bottom, rammed slightly, and on being drawn up showed by the bruising of the ends how they were to be cut to fit the rock bottom. After being shaped they were again put in place and rammed, and withdrawn a second time to determine whether further fitting was necessary. Against the sheeting was thrown the strippings from the excavations for the dam and power-house, a mixture of sand and loam, and on top of this a quantity of rip-rap.

*Foundation.*—It was found that the rock bottom for the foundation of the power-house was of the same hard gneiss which had been examined, before the work commenced, on the banks of the river and the islands near the proposed site. Near the western end of the power-house, however, the rock became more dense, contained less mica, and finally merged into a very hard and dense trap, quite similar to that quarried at Conowingo and used in the concrete and for pudding stones. Examination showed it to be a dike which ran to Fry Island and then disappeared. Both the trap and gneiss were excellent foundations for the heavy structures, and test holes drilled the whole length of the work showed the same high quality of rock for a depth of 40 feet below the river-bed. The surface rock which was considerably eroded and fissured was removed, and at the shore end of the power-house about 50,000 cubic yards of the solid rock had to be taken out. The surface of the rock was then thoroughly cleaned, and a layer of cement grout spread over it preliminary to placing the concrete. The amount placed at any one

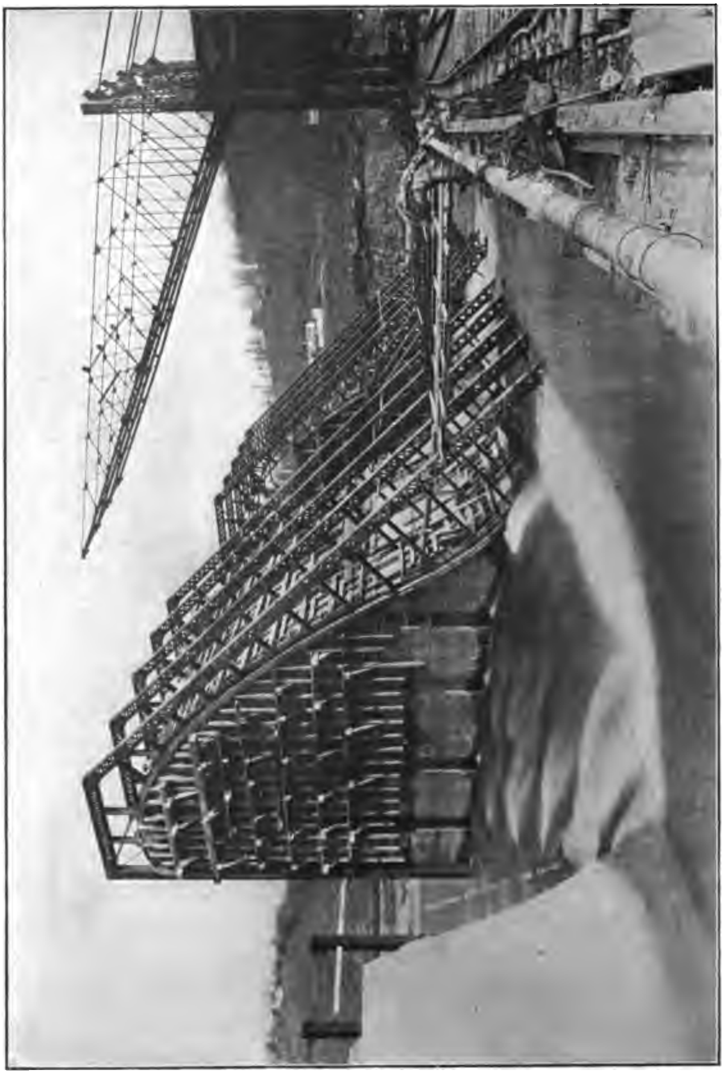


FIG. 111.—STEEL FORMS FOR SPILLWAY SECTION OF DAM.

time was governed by the strength of the forms, very close supervision being given so as to guard against bulging. The bond between successive sections is secured by embedding pudding stones in the surface of the work which is to be left to set. When the next course is added, the surface is first thoroughly swept with wire brushes, and then washed. Cement grout is spread over the surface, and the concrete work continued.

*Forms.*—The forms for the turbine intakes, and chambers, and draft tubes were quite complicated, as everything is built of plain concrete. They were carefully designed and built by experienced form builders. In order to fashion the complicated curves on many of the forms, sheet iron and bass wood were used, the latter being bent into shape after being steamed. The forms were very heavily braced and tied across when possible by iron rods, as any bulging or displacement would result in altering the carefully designed water passages, and cause a loss of head by obstructing or changing the course of the flowing water.

The forms for the dam consist of structural-steel bracing completely spanning the section of the dam, and resting on two shoes, one on the upstream and one on the downstream side. They are placed 10 feet on centres, and the spaces between them are filled with framed wooden cradles bolted to the steel forms, and having the curves of the surface of the dam. The steel forms consist of a post with a total height of 57 feet supporting a rafter which runs over the apron, and rests on a shoe at a horizontal distance of 68 feet $2\frac{7}{8}$ inches from the shoe under the post. Beneath the inclined rafter is carried a 12-inch $20\frac{1}{2}$-pound channel having the exact curve of the apron. On the bottom of the channel is a 2-inch timber, bolted to it, and having a width of 1 foot $9\frac{1}{2}$ inches. Bolted to this strip are uprights 3 inches wide and 6 inches high on each side, having bolt holes through them by which the cradles are fastened between the steel frames. The cradles are each 8 feet $2\frac{3}{8}$ inches long and 4 feet $2\frac{3}{4}$ inches wide, and each one is numbered according to an erecting diagram, for its proper place on the dam. On the channel sections the dam is being built in 40-feet piers, with 40-feet

openings between them. For these piers five of the steel forms were used and braced together by diagonals, and by a large box beam connecting the forms above the crest of the dam. At the shore of Fry Island, where the section was changed, the steel forms could not be used because of the warped surface connecting the sections. Wooden-braced forms were therefore put in place, and the value of the steel forms was demonstrated by the difficulty experienced at this point. The steel forms were used on the island section by merely unbolting the rafter at the center and allowing the two parts to overlap and pass each other, the lower part of the apron having the same curve on both sections, thus obviating the necessity of having two distinct sets of forms. The forms and cradles were placed, removed, and transported along the dam by the large cranes. It was not found necessary to provide any means for holding the forms down, as their weight alone was sufficient, but wires were passed through the dam, tying the vertical post and the rafter together to prevent the latter from bulging. An additional advantage of the steel forms lies in the saving in instrument work, it being necessary to set only the shoes with transit and level.

## THE TAYLOR'S FALLS-MINNEAPOLIS TRANSMISSION SYSTEM.

*Abstracted from The Electrical World of July* 6, *September* 7, *and October* 5, 1907.

THERE has recently been put into operation at Taylor's Falls, on the St. Croix River, 40 miles from Minneapolis, a water-power plant of a present capacity of 10,000 K.W. and an ultimate capacity of 20,000 K.W. It has been erected for the purpose of supplying power to the Minneapolis General Electric Company, which is the central station company of Minneapolis. This water-power plant and the transmission line and distribution system connected with it are among the notable recent engineering works of the country. Its capacity is sufficient to take care of all the present electric-light

and power business in Minneapolis. The purpose of this article is to describe the water-power development of the falls.

*Hydraulic Development.*—The St. Croix River is an excellent stream for water-power purposes, because it is fed by many lakes which act as storage reservoirs. The dam at Taylor's Falls is 50 feet high and 740 feet long. A much shorter dam would have been sufficient to obstruct the flow of the river, but this length was given to provide a long spillway for flood waters. A map of the dam,

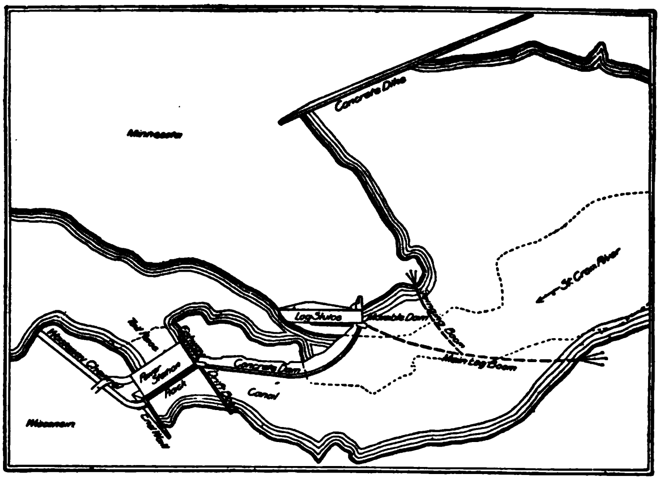



FIG. 112.—MAP OF WORKS AT TAYLOR'S FALLS.

power plant, and river in the vicinity of the falls is shown in Fig. 112. The original course of the stream is shown by the dotted lines, the river being naturally very narrow at this point.

The power station is located on what was formerly a point of land, excavation having been made for the tail-race. By virtue of the tail-race excavation an effective head of 56 feet is obtained, although the dam is only 50 feet high. The location is almost an ideal one for the development of large power and storage capacity without excessive flooding of upstream land. The St. Croix River runs between high, narrow banks for the entire 11

miles up-stream influenced by this dam. The only construction work which had to be done to prevent overflowing extensive land was the building of a concrete dike on the Minnesota side of the river, as shown in Fig. 112. Eleven miles above Taylor's Falls is Never's Dam, owned by the same company and maintained for the purpose of storing water with which to supply the Taylor's Falls power plant in dry seasons.

As seen by the map (Fig. 112), provision has been made for a log sluice on the Minnesota side of the river, entrance to which is through a bear-trap dam. A log boom extends across the river so as to divert logs to the sluice, and a swinging boom protecting the sluice is also placed above the bear-trap dam. A fishway is placed at one end of the power station, as indicated.

The dam is simply a piece of solid concrete construction resting on bed-rock. The rock used in this construction was obtained on the spot. In many cases large chunks of trap rock were cleaned, dropped into place and surrounded by concrete, 6 inches on all sides. The concrete used in the dam was a mixture of one part cement, three of sand, and five of crushed stone from trap rock found on the place. Samples of each carload of cement were tested at the construction office at the falls. The first part of the dam was built with openings in the bottom through which the river was diverted by a cofferdam when the remaining portion of the dam was being built. The forebay is protected by a drift boom located as shown in Fig. 112. Fig. 114 is a view of the forebay showing the ice and drift racks, which are easily accessible to workmen with rakes. A crane has been left in position for the purpose of lifting heavy driftwood out of the forebay if necessary. The dam proper extends clear through under the power-house, and the power-house building is erected on the face of the dam. Fig. 115 shows a cross-section of the dam at the power-house, the power-house foundation, showing the position of the intake pipe, turbines, and draft tubes. The intake pipe, 14 feet in diameter, has an elbow leading into the turbine casing. From the top of this elbow a 3-foot air vent pipe is led off. Over the middle of the turbine casing is an opening

through which parts can be hoisted out for replacement or repairs. As will be seen from the cross-section drawing of the power-house

FIG. 113.—VIEW OF POWER-HOUSE AND PART OF DAM.

(Fig. 116), there is an I-beam on the ceiling of the wheel gallery which is located directly over this opening into the turbine casing.

This I-beam carries an electric travelling hoist which can be run over any one of the turbines while repairs are going on, and with it parts can be carried to the end of the power-house. From the turbine casing two draft tubes $7\frac{1}{2}$ feet in diameter drop to the tail-race.

*Power-House.*—Before proceeding to a description of the gates, gate-operating machinery, and turbines, the general arrangement of the power station will be considered further. On the lower floor

FIG. 114.—FOREBAY AND RACKS.

is the generator-room, spanned by a 25-ton, 3-motor crane. On the second floor are the transformer-rooms and switchboard. Each bank of three transformers is in a separate fireproof room and arranged to roll out onto the gallery under the main crane. On the same floor as the transformers, but separated from them, is the operating switchboard located so that the attendant can see from the gallery what is going on in the generator-room. The 50,000-volt leads from the transformers go up through the floor to oil switches and then into bus compartments in a cell-room. From the cell-room the 50,000-volt conductors pass up to oil switches and from there to the protective apparatus and out to a steel tower, from which a span is made across the river to connect it to the pole line to Minneapolis.

In the uppermost story of the power plant is the motor-operated gate-lifting mechanism.

*Turbines.*—There are four turbine units each direct-connected to a 2,500-K.W. generator. Each of these turbine units has four

runners 36 inches in diameter mounted on the same shaft. At 277 r.p.m. the turbines are rated at 4,200 H.P. each with 55 feet head; at 48 feet head, 3,400 H.P.; at 45 feet head, 3,150 H.P. The run-

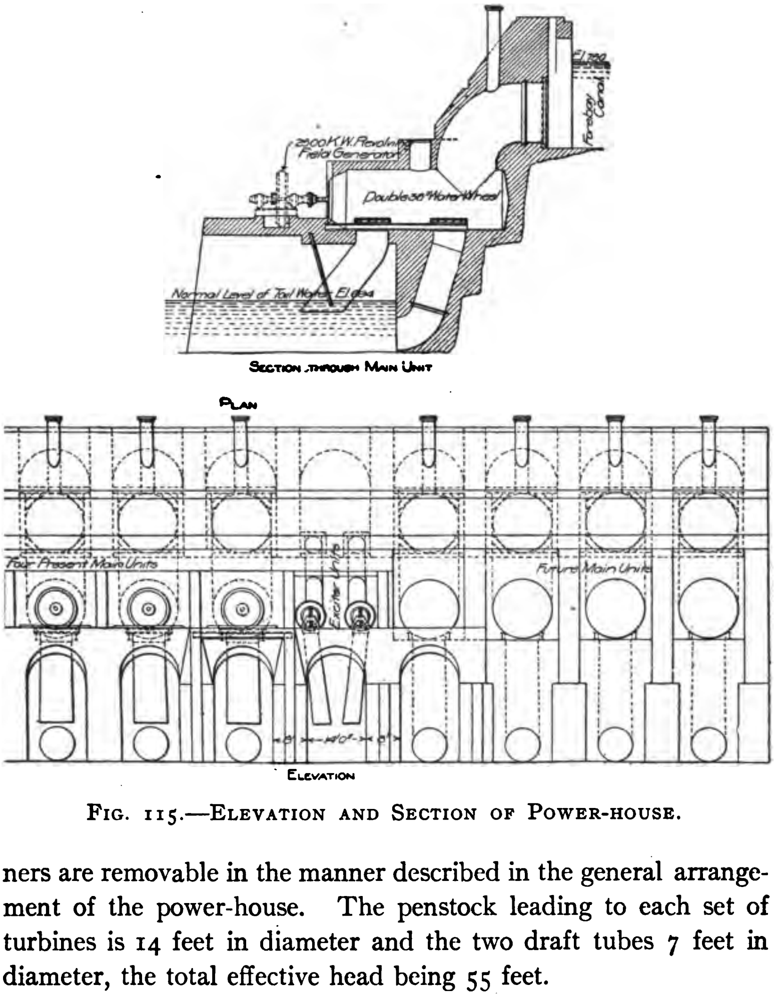



FIG. 115.—ELEVATION AND SECTION OF POWER-HOUSE.

ners are removable in the manner described in the general arrangement of the power-house. The penstock leading to each set of turbines is 14 feet in diameter and the two draft tubes 7 feet in diameter, the total effective head being 55 feet.

The water-wheel speed is regulated with Lombard governors, these governors controlling the gates with oil pressure. The

oil-pressure tanks for the four governors are connected in multiple. The wheel units can be started, stopped, and controlled from the switchboard by small motors mounted on the governor heads and so connected as to raise or lower the running speed of the governor. These governors were installed under a guaranty that an instantaneous variation of 20 per cent. in the load on the generator should not cause more than 2 per cent. speed variation, and that only for 4 seconds. In the case of the opening of a short-circuit on the generators the speed is guaranteed not to change over 12 per cent. and to return to normal within 7 seconds or less.

The two turbines which drive the exciters have each a runner

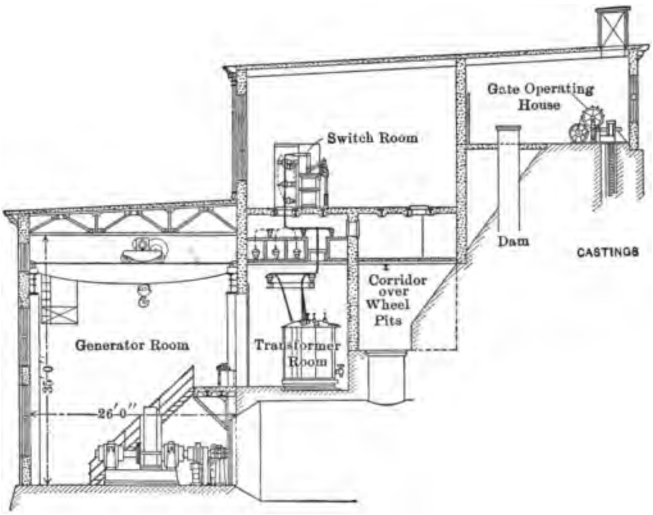



FIG. 116.—SECTION OF POWER-HOUSE.

18 inches in diameter. These turbines are rated at 200 H.P. at 525 r.p.m. with 55 feet head. Besides being direct-connected to an exciter, one of these turbines can be connected through a friction drive to a rotary fire pump for fire purposes. The friction drive is of the grooved-pulley type.

*Generators.*—There are now installed four 2,500-K.W., three-phase, 60-cycle, 2,300-volt generators. The power-house has room

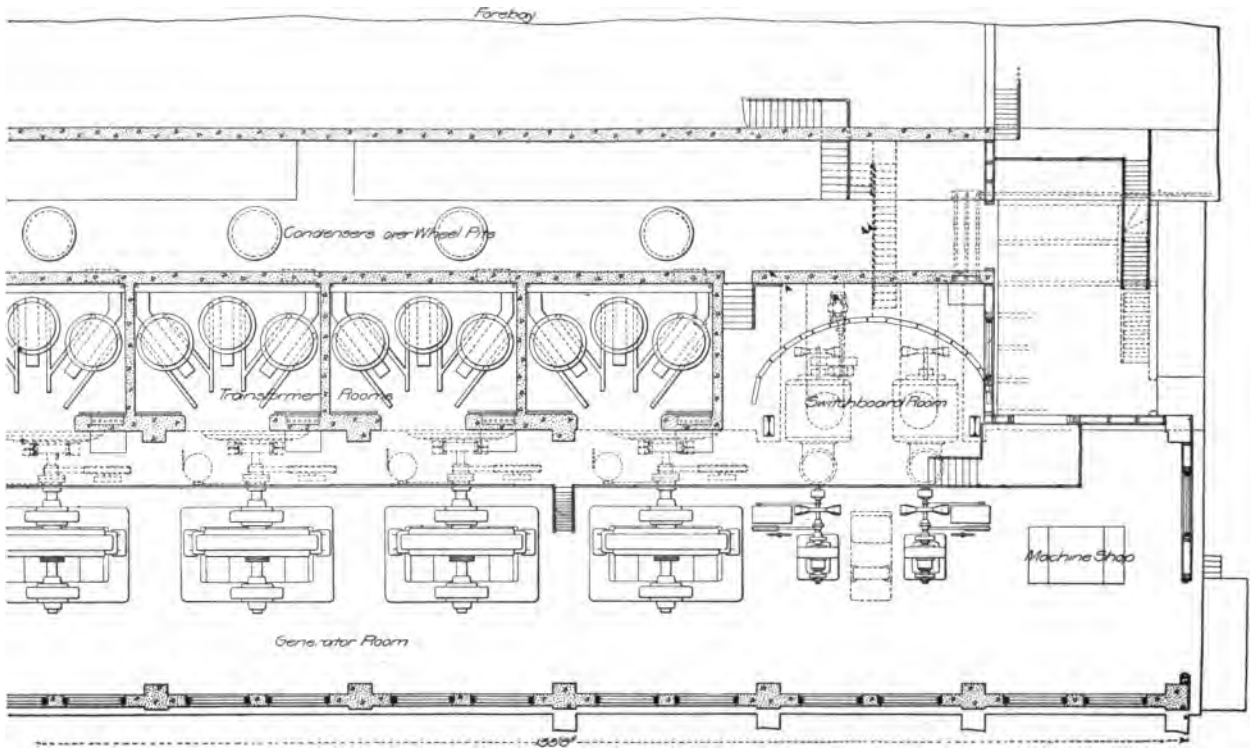



FIG. 117.—PLAN OF POWER-HOUSE.

for one more generator of this size at the end now occupied by the machine shop, and by extending the building three additional generators can be installed, making a total capacity of eight 2,500-K.W. machines, or 20,000 K.W. The generators are guaranteed to take a load of 2,500 K.W. continuously and a load of 3,125 K.W. for two hours without exceeding the usual allowable temperature rise.

FIG. 118.—INTERIOR OF POWER-HOUSE, TAYLOR'S FALLS.

Although their normal speed is 277 r.p.m., they are calculated to withstand 554 r.p.m. without excessive strain. If driven at constant speed the drop in voltage between no load and full load with constant field excitation is 6 per cent. The field-excitation current is 225 amperes at 125 volts. The efficiency at full load is 96 per

cent., at three-fourths load 95 per cent., and at one-half load 93 per cent. The field-puncture test is 1,500 volts, and the armature test 5,000 volts.

The two water-wheel-driven exciters are 100 K.W., 125-volt machines, direct-connected to the water-wheels before described. These exciters, which have an overload capacity of 150 K.W. for two hours, are compound-wound with a series winding sufficient to maintain constant voltage from no load to full load; or, in other words, a flat characteristic. Their effective voltage can be varied by the rheostat between 90 and 130 volts. The efficiency at full load is 90 per cent., one-fourth load 80 per cent., and at 50 per cent. overload 89 per cent. In Fig. 118 is seen a general interior view of the generator-room, showing the machines just described, one of the exciters, however, not having been installed when this view was taken. Room has been provided for the installation of a 100-K.W. motor-driven exciter between the two other exciters when the power-house is extended.

*Transformer-rooms.*—The transformer-rooms or -cells are among the most interesting features of the plant. The doors opening into these cells can be seen at the gallery on the right in Fig. 118, above each generator. There is one bank of transformers for each generator, and ordinarily a generator and its bank of transformers are considered as a unit, although provisions for separating them are made in the wiring scheme of the station, which will be described later. A view into one of the transformer cells is shown in Fig. 119. The transformer cells are of solid concrete with a fire-door opening onto the gallery in front. The fire-doors are held open by fusible links to allow the doors to slide shut in case of fire. The transformers are each of 900 K.W. The primary voltage is 2,300 and the secondary voltage 50,000. They are oil and water cooled, the water being piped from the forebay. The oil can be drained from the transformers by opening a valve which is accessible in the wheel gallery behind the transformer cells; thus, in case of fire in a transformer case, the oil can be drained off without entering the cell, and the cell can be kept closed. As shown in Fig. 119,

each transformer is mounted on a four-wheeled truck and there are tracks converging toward the door so that any one of the transformers can be run onto the gallery, where it can be picked up by the travelling crane.

On the top floor of the building is an electrically heated oil-treating tank 4 feet in diameter × 8 feet long, in which enough

FIG. 119.—TRANSFORMER CELL.

oil can be treated for one transformer. It contains electric heating coils requiring a maximum of 45 K.W. When the oil is heated with these coils a motor-operated vacuum pump 8 inches in diameter × 6 inches stroke pumps out the steam that may be formed from any moisture in the oil. The power station is piped for transformer and switch oil.

*Switches and Wiring.*—Each generator is connected directly to its bank of step-up transformers without the intervention of any oil switch, although there is a set of disconnecting switches in the leads of each generator before they come to the current and poten-

tial transformers. In ordinary operation generators are connected in parallel by means of the oil switches on the 50,000-volt side of the transformer, thus putting them in parallel on the 50,000-volt bus-bars. The 50,000-volt bus-bars are therefore the usual operating bus-bars of the station. One set of 2,300-volt bus-bars is operated, however, and branches from the leads of each generator are taken to oil switches, by which each generator can be connected to the 2,300-volt bus-bars. These 2,300-volt bus-bars are ordinarily intended for use in supplying 2,300-volt current in the vicinity of the power plant. They can also be made a means of connecting a generator to a bank of transformers other than the one to which it is normally connected, as might be necessary in case of the break-down of a generator and a bank of transformers connected to another generator. The wiring scheme is designed for the completed power station; but not all of the circuits have as yet been installed. There is now a single set of 50,000-volt bus-bars. Provision is made for a double set of 50,000-volt bus-bars and an extra set of switches whereby each generator can be connected with either set of bus-bars. Static dischargers are connected between the generators and transformers, being located in the transformer cell-rooms. While provision is made for two outgoing 50,000-volt transmission lines, at present there is only one such line. There is an oil switch between the 50,000-volt bus-bars and the line.

The 2,300-volt leads from each generator are carried in fibre conduit in the floor to recesses or cabinets in the wall at the right in Fig. 118. In these cabinets are the current and potential transformers from which low-tension wires are taken to the instruments on the switchboard in the gallery. The generator leads then pass up to the primaries of the step-up transformers in the transformer-cell rooms above. The 50,000-volt secondary leads of these transformers are connected in delta in the transformer-room and then pass up through circular openings in the floor, filled with plate glass, to the bus-bar cells or compartments, to which a part of one floor of the power station is devoted. From the bus-

bar cells the wires lead up through similar circular floor openings to the 50,000-volt oil switches.

The oil switches (which have a capacity of 1,500 amperes at 50,000 volts) are considerably larger than are needed in this plant. They were originally built for another plant, but were sent to Taylor's Falls because of the urgency of delivery. They are solenoid-operated and in reality consist of three enormous single-pole oil switches mechanically connected. At the right in Fig. 120 is

FIG. 120.—50,000 VOLT, OIL SWITCHES.

seen the row of holes left for the high-tension conductors to the second set of 50,000-volt oil switches. The other openings in the floor are recesses left for oil piping. From the oil switches controlling each bank of transformers the conductors pass down again to the 50,000-volt bus-bars. In the case of the oil switch connecting the 50,000-volt bus-bars to the transmission line the wires pass up from the oil switches to the series transformers and choke coils and thence out of the building. The general arrangement of

current transformer, choke coil, and lightning arrester for one phase of the 50,000-volt line is shown in Fig. 121. Hook disconnecting switches are provided on each side of all high-tension apparatus to provide for its isolation in case work is being done upon it.

The operating switchboard is comparatively small and simple, all of the operating switches in the main circuit being designed for remote control by low-tension circuits. These low-tension cir-

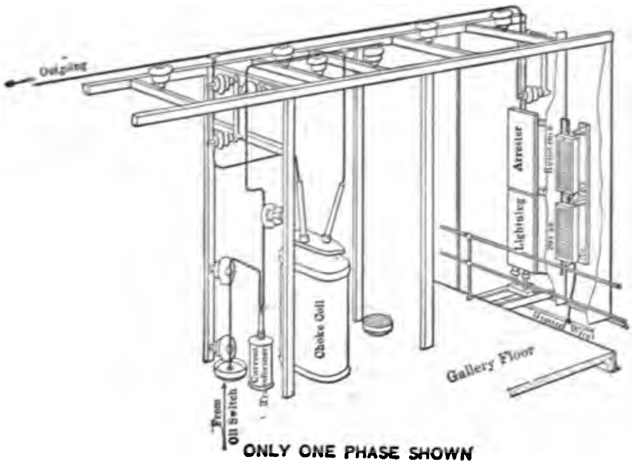



FIG. 121.—CONNECTIONS OF TRANSFORMER, CHOKE-COIL AND LIGHTNING-ARRESTER.

cuits are obtained from the exciter. There are two negative exciter bus-bars, one of which is for local miscellaneous use in the power-house and the other for the field excitation. There is one common positive bus. Each exciter has simply a double-throw, single-pole switch for connecting it to either negative bus-bar, and an automatic circuit breaker. The totalizing panel for the board forms the centre of a semi-elliptical arrangement of switchboard panels. This totalizing panel contains an indicating wattmeter which, by means of a commutating switch, can have its connection changed, so that, when the load is light, almost a full scale

reading can be obtained, applying, of course, the proper constants to the reading to give the correct result. The other features of the board are those ordinarily found in such installations.

*Gate-lifting Mechanism.*—The main gates which admit the water from the forebay into the penstocks are raised and lowered by a motor-operated mechanism. A motor mounted on the ceiling drives a shaft that runs the length of the power-house. From this shaft is driven a counter-shaft at each gate. This countershaft has a worm-gear driving pinions engaging in racks on the gate. It is, of course, intended that only one gate shall be operated at a time. The mechanism for any gate can be brought into operation by throwing in a clutch. The controller for the motor is located on one wall of the building and is connected by a sprocket chain to a shaft which has two hand wheels at every gate, so that the motor can easily be stopped and started from any point. The height of the water in the forebay is continuously indicated and recorded by a Frieze water-level recorder.

The regular operating force of this station, including both night and day shifts, consists of one chief engineer, two operators, and two oilers.

## The Line.

The transmission line is 40.6 miles long and is designed to carry the total present capacity of the Taylor's Falls plant—namely, 10,000 K.W.—with a line loss of 6 per cent. and a voltage drop of 10 per cent. It is built in almost an air line from the west side of the St. Croix River and Taylor's Falls to a substation at the city limits of Minneapolis. At the Minneapolis substation are step-down transformers for reducing from 47,500 to 13,800 volts. From this substation the transmission is at 13,800 volts to the various stations and substations of the Minneapolis General Electric Company.

*Pole Line.*—A right of way 60 feet wide was purchased for the entire line. The right of way, however, is not fenced in, and farmers are allowed the use of the land just as before the purchase. The

general direction of the line is northeast and southwest, so that it cuts diagonally across all fields. As the highways follow the section and half-section lines, the nearest highway zigzags across the line from one end to the other. As the country is dotted with small lakes, a number of these had to be crossed, and for such crossings

FIG. 122.—TRANSMISSION LINE.

steel towers were employed. Fig. 122 is from a photograph of the typical straight-line construction. This shows also one of the telephone booths. Fig. 123 is a drawing showing the dimensions on a standard straight-line pole. The separation between wires is 6 feet. The conductors are No. 4-0 stranded, semi-hard-drawn copper. A four-pin telephone cross-arm is placed 7 feet below the transmission line. The poles are set from 100 feet to 120 feet

apart and vary in length according to the local conditions and contour of the country from 40 feet to 60 feet, the object of this being,

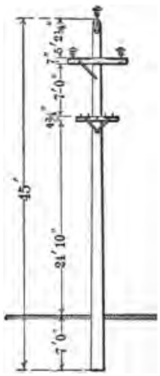



FIG. 123.—STANDARD POLE.

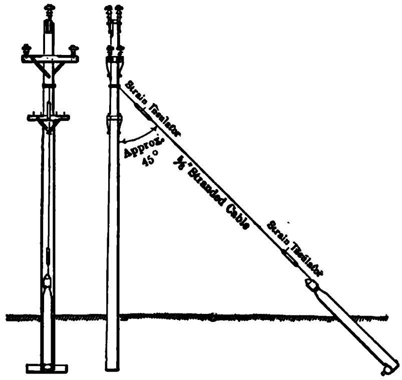



FIG. 124.—GUYED POLE.

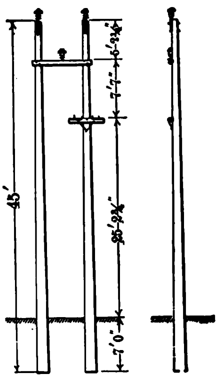



FIG. 125.—TRANSPOSITION POLE.

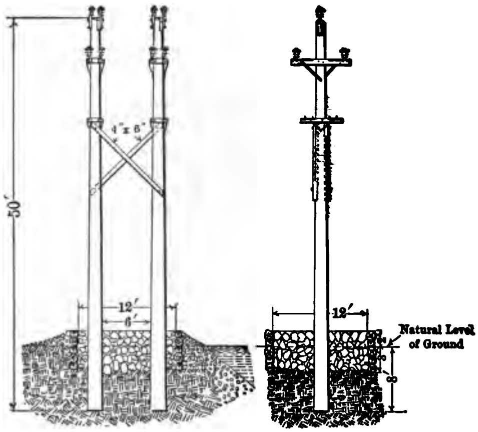



FIG. 126.

of course, to avoid too sudden changes in the level of the conductors. The following pole dimensions were specified:

| | |
|---|---|
| For a length of 40 ft. | Tops 8 ins., butts 15 ins. |
| For a length of 50 ft. | Tops 9 ins., butts 16 ins. |
| For a length of 60 ft. | Tops 10 ins., butts 18 ins. |

The cross-arm braces are of 1½-inches × 3-16-inch angle iron 3 feet, 7⅝ inches long.

The main transmission cross-arms are 7 feet 4 inches long and 5 × 7 inches in section. There are in all 12 telephone booths in 40.6 miles of line. There is a patrolman's cottage at the half-way point, the other patrolmen living at Taylor's Falls and Minneapolis. For crossing lakes four sizes of steel towers are used—40, 45, 50, and 60 feet in height. Conductors are spaced 7 feet apart on towers. There are 27 steel towers on the line on account of the large number of bogs and lakes to be crossed. The telephone wire is No. 10 semi-hard-drawn copper. Double cross-arms are used at all curves and pronounced changes in the profile.

Fig. 126 is a drawing giving dimensions and foundation details

Fig. 127.—Transposition of Conductors.

for use when crossing a narrow stream. Fig. 127 shows the arrangement at the transposition of the transmission conductors. A transposition of one-third turn occurs every 3½ miles. A double pole is used for this purpose. The telephone line is transposed

every tenth pole. Fig. 128 shows a pair of steel towers at the crossing of Leedholm Lake.

*Insulators and Pins.*—The transmission-line insulator used is known as S. & W. No. 1, made by Locke. A cross-section of this

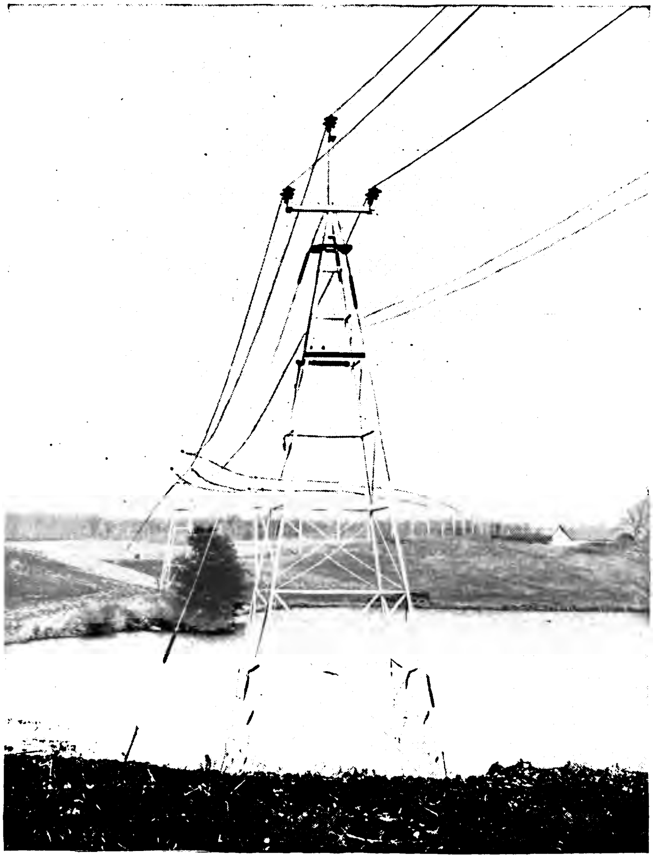


FIG. 128.—STEEL TOWERS.

insulator is shown in Fig. 129. It consists of four parts held together with neat cement. These insulators are shipped in crates, assembled, but without pins. The crates were provided with holes

just the right size to take in the pin. The cementing in of pins was done before the insulators were uncrated, the crate thus serving the purpose of a template to hold the pins in position while the cement dried. The insulator, as seen by the drawing, is 12¼ inches high by 14 inches in diameter over all. The four parts were tested before assembling with a 60-cycle, 200-kilo-volt-ampere testing set.

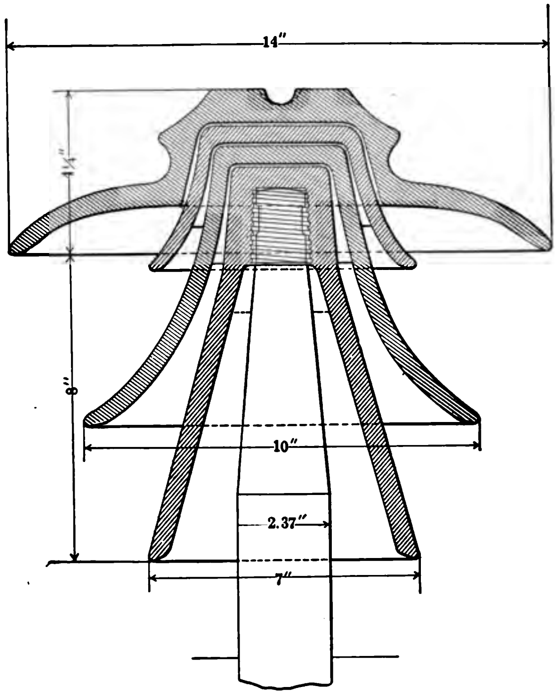



FIG. 129.—INSULATOR.

The top piece withstood a test pressure of 60,000 volts; the second shell, 40,000 volts; the third shell, 50,000 volts; and the fourth inner shell or centre, 50,000 volts. The assembled insulator without cement was tested at 120,000 volts.

The strain insulators, as shown in the guy wire in the illustrations, consist of pieces of oak 2½ inches × 2½ inches and 30 inches

long, boiled in linseed oil. A tie wire of No. 2 solid copper is used for fastening the No. 4-0 stranded conductor on the 50,000-volt insulators.

The insulator for the telephone line is a double petticoat 2,300-volt porcelain insulator placed on a locust pin with a white-pine cross-arm. The cross-arms of the transmission line are of fir, unpainted.

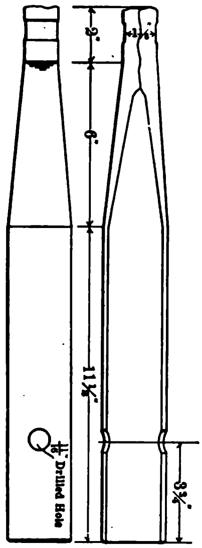



FIG. 130.—INSULATOR PIN.

The pins for the transmission insulators are made from 2-inch extra-heavy steel pipe, with ends swedged down for cementing into the insulators. Fig. 130 shows the pin used on the cross-arms. This pin is held by a bolt passing at right angles through the cross-arm. The pins used on the pole tops have their lower ends flattened so as to bolt against the pole. Two pins out of every 100 are tested and must stand a lateral strain of 2,000 pounds applied at a point 1 inch above the top, without yielding.

*Lightning Protection.*—Few transmission lines have had so much attention given them as regards lightning protection. Minnesota thunder-storms are very severe, and it was felt that with a line of so much importance, upon which the electric-light and power service of a great city might be dependent there was every reason for obtaining the best in lightning protection. Of the lightning protection appliances about to be described, many are of a partially experimental nature and have been put up with a view to determining points about which there is at present considerable uncertainty.

At each end of the line and in the middle, horn-type lightning arresters have been installed in accordance with Fig. 131. A rectangular cross-arm frame is built between four poles, and the necessary insulators mounted on these cross-arms. The horn

spark-gap is adjustable from zero to 12 inches. Underneath the arrester is a platform, also mounted on transmission insulators.

A water-column resistance can be inserted in the series with a

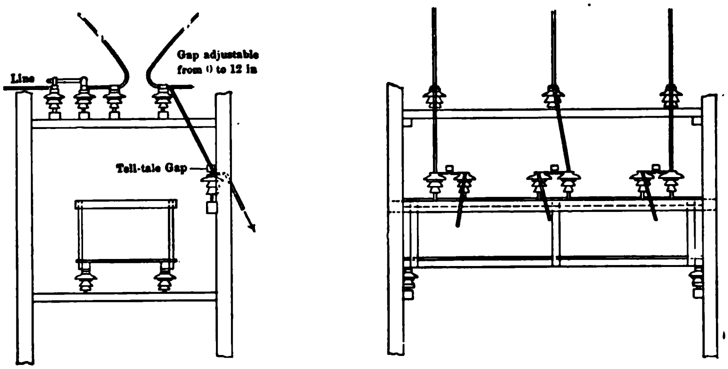



FIG. 131.—HORN LIGHTNING ARRESTERS.

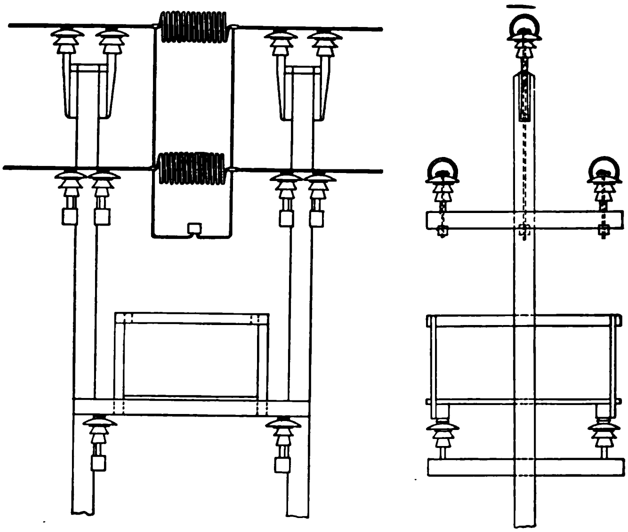


FIG. 132.—CHOKE COILS.

ground wire from this arrester, this water-column resistance being described later. The choke coil used in connection with lightning

arresters is shown in Fig. 132. There is also a platform under these choke coils, so that the paper in the tell-tale spark-gaps, which are placed in shunt around choke coils, can be renewed. A tell-tale spark-gap which has been used in large numbers in getting records of static discharges on this line is shown in Fig. 133. Fig. 134 shows the framing used in connection with the adjustable spark-gaps, tell-tale spark-gaps, and fuses installed for obtaining records on discharges.

The water-column resistance before referred to, which can be used in series with the ground wire of the horn arrester, is shown in Fig. 135. It consists of three galvanized-iron tanks or funnels, one for each leg of the circuit. These are mounted on transmission insulators, and each is connected to the ground wire from a horn arrester. In the bottom of these tanks are five nozzles, one or all of which can be turned on according to the amount of water-column resistance it is desired to insert.

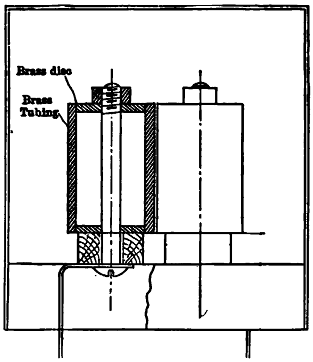



FIG. 133.—TELL-TALE SPARK-GAP.

Water from these nozzles falls into a grounded iron pan. This iron pan can be adjusted in height, as shown by the drawings, being suspended on pulley blocks. The water supply is piped to the arrester tanks by pipes discharging several feet above the tank. For purposes of obtaining records, every pin on every third pole of the transmission line has been grounded through a tell-tale spark-gap. Several experimental schemes of overhead grounds have also been installed on different portions of the line to determine the best construction. One form of overhead ground is to place a grounded wire at the centre of the transmission-wire triangle. Another plan has been to place grounded wires directly above the two lower wires of the triangle. Still another plan has been to place

a lightning rod on each pole with its point above the top wire of the transmission triangle. This lightning rod is fastened to the pole, and is bent out around the top transmission wire to keep it

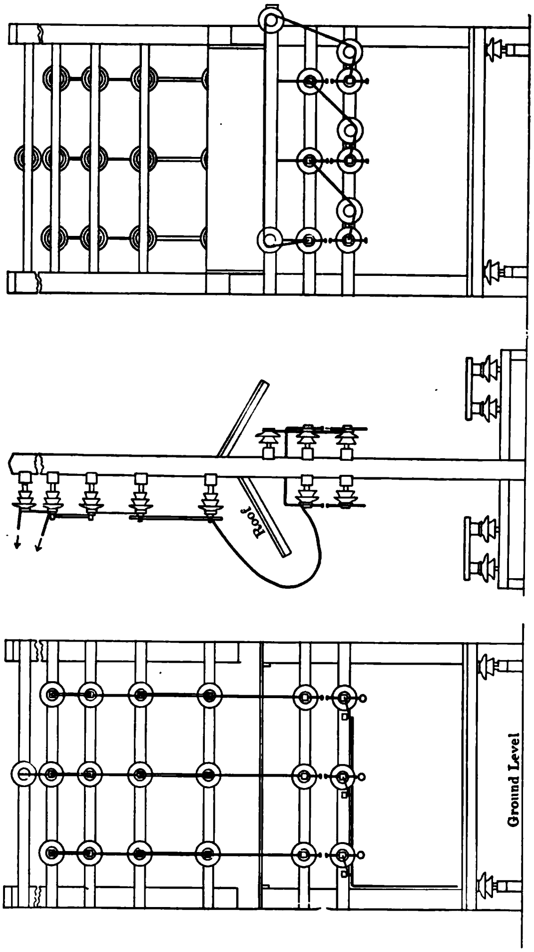



FIG. 134.—FRAMEWORK FOR SPARK-GAPS AND FUSES.

a safe distance away. Another lightning-rod scheme installed is that of placing lightning rods on separate poles set alongside the transmission line, the rods extending about 25 feet above the level

of the top transmission wire. Tell-tale spark-gap boxes are inserted in all ground wires. The line is looked after by four patrolmen.

*Distributing System.*—The general plan is to decrease the E. M.F. from 47,500 to 13,800 volts at the city limits. From a step-down substation at the city limits 13,800-volt, three-phase lines connect with the two old generating stations of the company, and

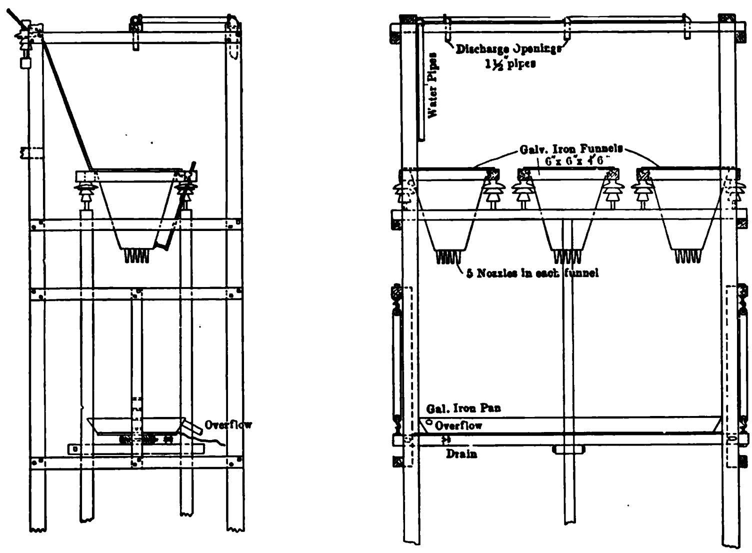



FIG. 135.—WATER COLUMN RESISTANCE.

also supply energy to a number of small distributing substations, from which it is distributed at 2,300 volts, three-phase, to large industries located in the immediate vicinity. It will be noted, therefore, that the distribution system possesses many features which have not heretofore been employed to any extent in large city systems.

*Substation at the City Limits.*—At the city limits, at a main receiving substation, energy is received from the 40-mile 50,000-volt three-phase line. The building is thoroughly fireproof, and

every precaution has been taken to prevent interruption of service, because all of the energy from Taylor's Falls must pass through it. This substation contains nine 900-K.W. transformers. Each transformer is mounted on a truck and can be run out onto a turn-table and from there over a track along the middle of the building to the door. The building is provided with concrete floors. Water for cooling the transformers is obtained from a deep well by means of a pump. There is also a cooling-pond

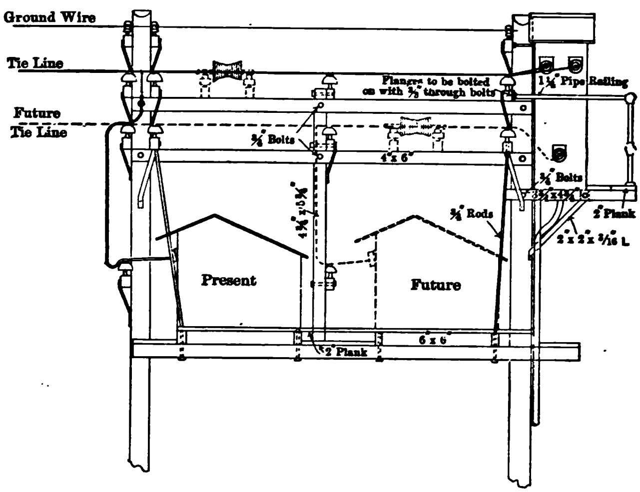



FIG. 136.—LIGHTNING ARRESTER TERMINAL POLE.

adjoining the station into which water is discharged after passing through the transformers. Water can either be circulated from the well or from the pond. The substation is provided with pipes for transformer, and switch oil, so that oil can be run into any transformer case. There is also an oil-treating tank similar to that in the power station, as described in the article on the power station. The second floor of this substation is the switchboard and switch-room, shown in Fig. 137. The 47,500-volt wires are kept on one side of the station, and the 13,800-volt wires on the other side. Some of the high-tension wiring in the upper part of this floor of

the building is shown in Fig. 138, where the 47,500-volt wiring is seen on the right. The general scheme of the wiring of this main substation is shown in Fig. 139. The incoming 47,500-volt transmission line, after passing the disconnecting switches, choke coils, and series transformers, is taken to a set of oil switches and thence through another set of disconnecting switches to the 47,500-volt bus-bars. The ultimate plan is to have two sets of 47,500-volt bus-bars which can be connected with an oil junction switch. Every

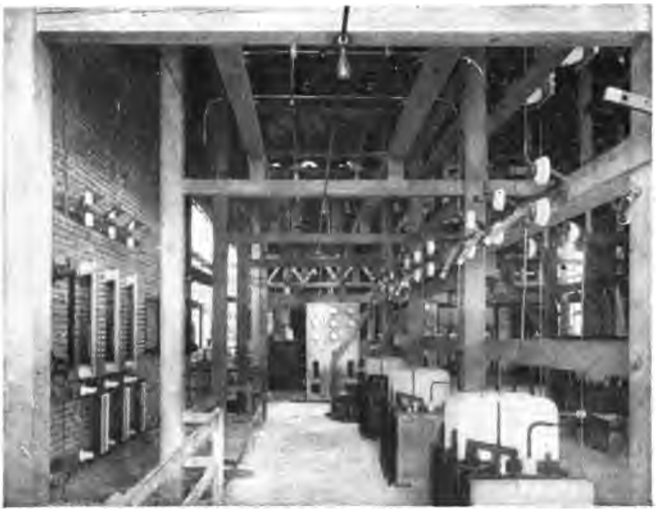


FIG. 137.—SWITCH-BOARD ROOM OVER TRANSFORMER ROOM.

other bank of transformers is connected to one set of bus-bars, and the remainder to the other set. The 13,800-volt terminals of the transformers are connected to two sets of bus-bars in a similar manner. The city transmission lines are taken off from these latter bus-bars and are led through oil switches and potential and series transformers to the transmission lines.

*The 13,000-volt Distribution.*—There are three transmission lines leaving the main substation, all of which lines feed into the Main-Street station of the Minneapolis General Electric

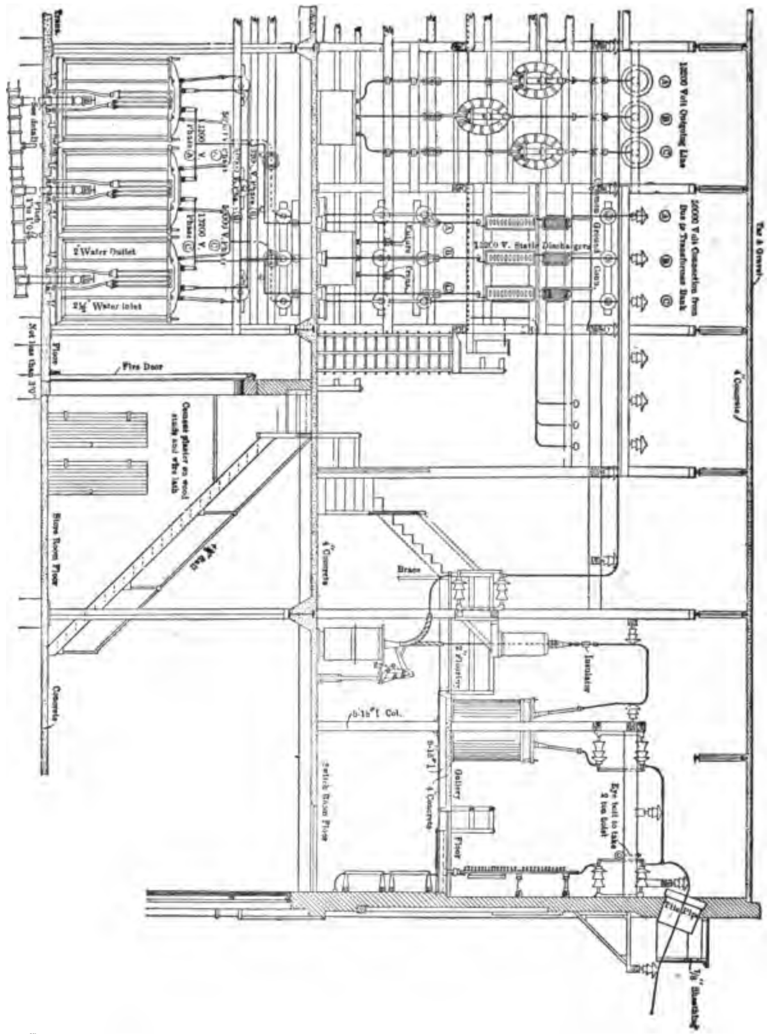


FIG. 138.—LONGITUDINAL SECTION OF MAIN SUBSTATION SHOWING WIRING.

Company. This station has heretofore been the principal generating plant. It contains both water-power and steam machinery, as will be briefly outlined later. This plant will act as a kind of distributing centre. At it the E.M.F. will be decreased

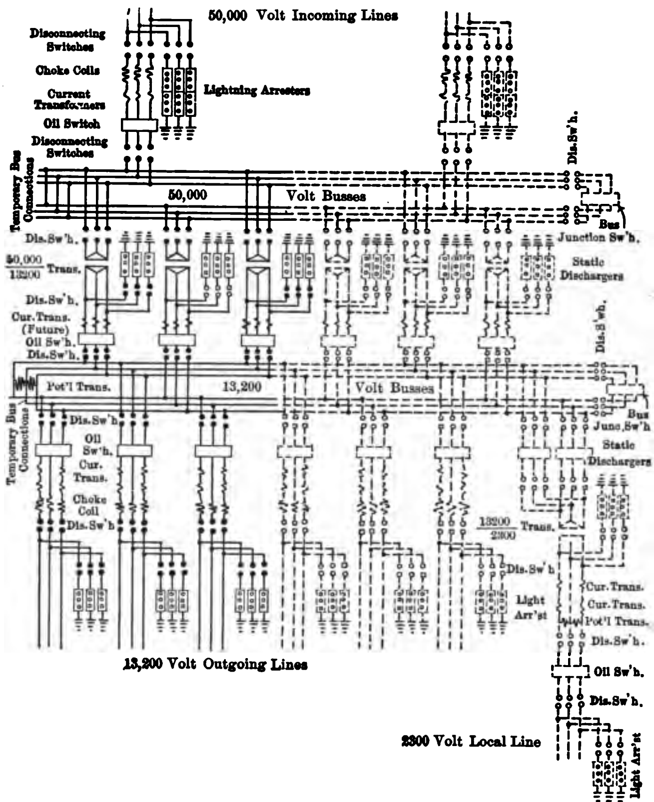



FIG. 139.—WIRING DIAGRAM OF MAIN SUBSTATION.

to 2,300 volts for single-phase distribution for lighting purposes over the entire city outside of the downtown district. The downtown district is served with direct current from the Fifth-Street station, which is connected with the Main-Street station by two 13,800-volt, three-phase lines, from which energy is obtained

for operating motor generators, step-down transformers, and rotary converters. The company's offices are in this substation; the building in this respect is very similar to the Edison buildings in a number of the large cities of the country. This station is well located to supply energy to the direct-current, three-wire network in the downtown district. The district is limited in area, extending only about half a mile in any one direction from the substation.

FIG. 140.—WIRING IN TOP OF SUBSTATION.

When the area increases more direct-current substations will be established.

The details of the overhead lines are of considerable interest, because of the use of an E.M.F. of 13,800 volts for general city distribution. On the standard pole top for the 13,800-volt lines there are no lower voltage lines. The top cross-arm is designed for use with grounded guard wires, as will be explained later. The transmission wires are placed 2 feet apart. On a pole used for both 13,800- and 2,300-volt lines at a substation, the 2,300-volt lines are placed on the lower cross-arm. An elaborate pole framing at a substation is shown in Fig. 141. This particular pole carries a telephone arm which is necessary on some of the lines.

Unusual provisions for lightning protection on the 13,800-volt lines had to be taken because of the severity of the lightning-storms and by reason of the fact that there are so many changes from overhead to underground lines. Two grounded guard wires are placed on the ends of the top cross-arm. At every third pole the guard wire is grounded to a coil in the bottom of the pole

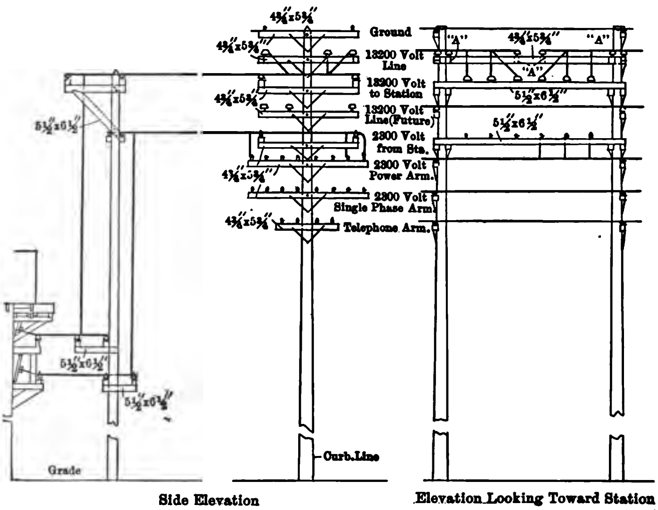



FIG. 141.—DIAGRAM OF POLE HEAD AT SUBSTATIONS.

hole for new poles or to a pipe driven in the ground near the old poles. The guard wires are mounted on 2,300-volt insulators.

All of the 13,800-volt lines are laid underground except those in very sparsely settled portions of the city. One of the lines leading from the main substation to a secondary substation passes underground at two railroad crossings before it reaches the underground district. Lightning arresters are placed at all points of change from overhead to underground. To do this, miniature houses of asbestos lumber were built on the pole tops. Fig. 136 shows the exterior appearance of these houses where the cable terminals are placed on the same poles. Here the cable is led up

into a terminal box and the choke coils are mounted between the poles. For the underground, 13,800-volt lines, cambric and paper insulated cables are used. Cambric is preferred to paper because it is less liable to become injured when handled roughly, and it is less susceptible to moisture. The cable has 6-32-inch insulation

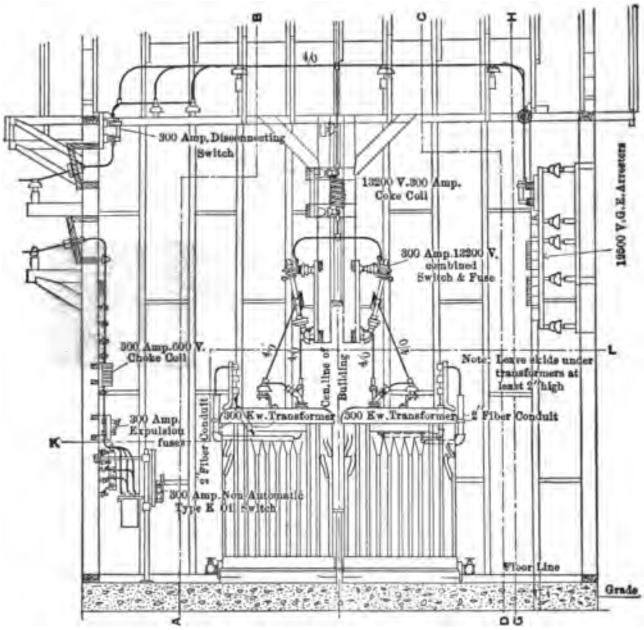


FIG. 142.—SECTION OF DISTRIBUTING SUBSTATIONS.

over each conductor, and 6-32-inch over all conductors, with $\frac{1}{8}$-inch lead sheath. In making a joint on this cable, after the conductors have been spliced, each conductor is wrapped with cambric, and cambric tape sleeves or thimbles are used to hold the conductors apart when the joint is being finished. The joint, after being covered with lead, is impregnated with Minerallac or G. E. 67 compound. The insulators on the 13,800-volt overhead lines are of the Locke No. $3\frac{3}{4}$ type, of brown porcelain, and are placed on birch pins.

*Distributing Substations.*—Between main substation No. 2

and the Main-Street station there are located along the three transmission lines various small substations. These substations, which form an interesting feature of the company's distribution, are intended for the purpose of supplying large power consumers only, and each contains simply three step-down transformers for reducing the E.M.F. from 13,200 to 2,300 volts, three-phase. There are no attendants at these substations. They are located near large power users; it is the intention to limit their output to 2,000 K.W. Since more power than this will almost never be required at one plant, it is considered better to build another substation when the 2,000-K.W. limit is reached rather than to increase the size of the existing stations. Both the 13,800, and the 2,300-volt lines are delta connected. The buildings are of galvanized corrugated iron. Since they are usually located in the railroad and manufacturing districts, their appearance is not of great importance.

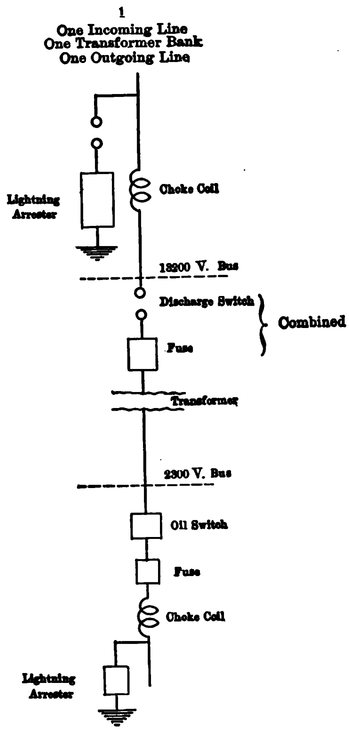



FIG. 143.—DIAGRAM OF CONNECTIONS

Fig. 142 shows the interior arrangement of one of these distributing substations. Fig. 143 shows the general scheme of wiring a substation, the three legs of the circuit being indicated as one wire. The 13,800-volt lines enter at one end of the building and pass down as shown in Fig. 143 through choke coils and a new type of compound switch and fuse rated at 300 amperes. The lightning arresters shown mounted at the right in Fig. 143 are of the new type of shunted-gap.

*Main-Street Station.*—The Main-Street station, which is located on the Mississippi River, in the heart of the city, was the principal generating station of the company's system before the circuits from Taylor's Falls were erected. This station is now operated partly by water power taken from the pondage above the St. Anthony Falls dam, partly by steam, and partly by electricity brought in over the tie lines from the main step-down substation of the Taylor's Falls system, mentioned in a previous article. The station is also arranged to act as an auxiliary to supplement the Taylor's Falls system at times of low water or accident.

The general layout of the station consists of line shafts on one of which is mounted a 1,000-K.W., 13,200-volt, three-phase machine which can be used to drive the shaft from energy received direct from the Taylor's Falls system or to be driven by the prime movers in the station, to deliver energy over the 13,800-volt tie lines to the step-down substations of the Taylor's Falls system or to the various substations scattered through the wholesale distributing district. The line shafts are normally driven by the water-wheels, which are three in number, with a total capacity of 2,400 H.P., assisted by the 1,000-K.W. machine operating as a motor. The relay capacity of the station is still further increased by a recently installed 1,500-K.W., 2,300-volt steam turbo-generator which is arranged to deliver energy directly to the 2,300-volt bus or through the tie-line transformers to the tie lines or to the before-mentioned motor on the line shaft. Energy is supplied from this station for 2,300-volt, two-phase, 60-cycle distribution, 500-volt, direct-current distribution and for both alternating-current and direct-current arc circuits from machines belted to the line shafts, from motor-generators and from constant-current transformers. In addition to its use as a motor or generator the 1,000-K.W. machine on the line shaft is used as a synchronous condenser to control the power factor of the system. The station is arranged to allow the installation of additional machines of this type, and the general tendency is to simplify and consolidate the apparatus.

*Fifth-Street Station.*—The Fifth-Street station is the main sub-

station of the Minneapolis system, located at the business centre of the city, where it is in the proper position to supply energy to the Edison low-tension system and to control the bulk of the business lighting. The station receives energy from the Main-Street station and the Taylor's Falls system; it contains steam auxiliary units and storage batteries. The steam auxiliary equipment consists of 600 K.W. rating of 230-volt, direct-current, direct-connected, engine-driven generators, 1,050 K.W. of 35-cycle rotary converters, 650 K.W. rating (on one-hour discharge) of storage batteries; two 100-K.W., three-phase, 125- and 250-volt rotary converters, and 1,125 K.W. rating of 13,800-volt air-blast transformers and feeder regulators for the proper control of the potentials of distribution from this station. The high-tension and a large part of the low-tension apparatus of the station is operated from a remote control switchboard.

## KERN RIVER NO. 1 POWER PLANT OF THE EDISON ELECTRIC COMPANY, LOS ANGELES.

*Abstracted from the Electrical World of August* 10, 17, 24, and 31, 1907.

THE Edison Electric Company of Los Angeles has completed and placed in operation a power plant on Kern River, which, while not surpassing any previous records of high heads utilized or length of transmission, does embody in its construction many distinguishing features some of which are pronounced departures from previous practice.

In capacity, the Kern River No. 1 power plant equals the rated capacity, 20,000 K.W., of the largest impulse-wheel plant previously in operation, and in overload capacity surpasses it. Its gravity conduit, constructed almost entirely of tunnels excavated through the mountains, is the most permanent and costly hydraulic waterway in the country. The pressure main, driven in the form of a tunnel, down the mountain slope, is probably the most unique feature of the installation and is a decided innova-

tion in power-plant construction. The water-wheels embody new features in the design of buckets, nozzles, and governors. In the electrical details of the station is incorporated the most modern apparatus. The transmission line is at present operating at 60,000 volts, which will later be raised to 75,000 volts. The length of transmission, 117 miles, is exceeded in only a few instances. Moreover, the steel towers and insulators are of special design.

The Kern River is the southernmost large tributary of the San Joaquin River, and has its head in the snow-covered slopes of Mt. Whitney and neighboring peaks in the Sierra Nevada Mountains.

Water for the Kern River No. 1 plant is diverted at a point about one-half mile below Democrat Spring, in Kern County, and about 14 miles up the river from the mouth of the canyon. A hydraulic conduit, consisting almost entirely of a series of tunnels, approximately nine miles in length, conveys the water through the mountains on the south side of the river to a forebay at a point about 900 feet above the river, and about two miles from the mouth of the canyon, where the plant of the Power Transit and Light Company, of Bakersfield, is located.

From the forebay, the force main continues down to the power-house in an inclined tunnel. The power-house is located on the bank of the river directly opposite the intake of the Bakersfield plant, and at an elevation of about 20 feet above the ordinary high-water level of the stream at that point. The tail-race of the station is designed so as to deliver the water to the river immediately above the diversion point of the Bakersfield plant.

The transmission circuits extend along the Kern Canyon and cross country to Los Angeles, 117 miles distant.

*Diverting Dam.*—The dam which is built to divert the water from the Kern River into the hydraulic conduit is placed on bedrock and is carried up to a point 1.25 feet above the flow line in the tunnel conduit, thus insuring a constant supply as long as the reservoir created by the dam is kept filled. In excavating for the dam, bedrock was found to exist at varying depths, the deepest portion being at the south end at about 35 feet below the stream

bed. A cofferdam was built to divert the river during the construction and while the fill overlaying the bedrock was being excavated. Trenches were then cut in the bedrock and holes bored, in which steel bars were driven in two rows across the canyon. The first layers of concrete were placed on the bedrock and secured to it by means of the trenches and the steel bars. Cyclopean concrete was the material of construction, the rock used being the granite found in the canyon. Many of the blocks were of large

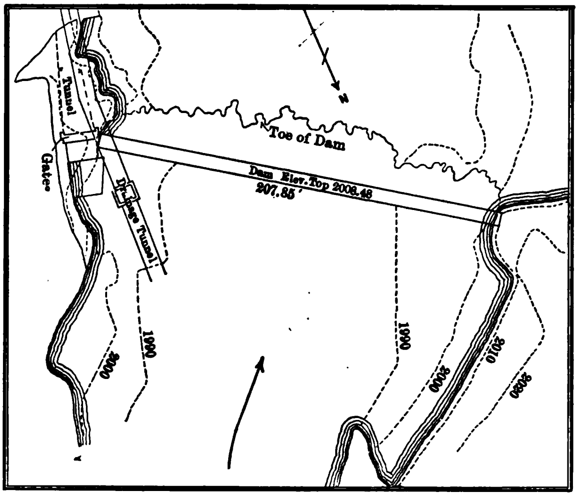



FIG. 144.—MAP OF KERN RIVER DEVELOPMENT.

size, some weighing several tons each. About 1,500 cubic yards of material were placed in the foundation and 3,500 cubic yards in the dam proper.

The dam is of the overflow type as shown in Fig. 145. Its length on the crest is 203.56 feet and its height above ordinary water-level in the river about 20 feet. At the base in the thickest part it is 52.81 feet wide. The crest has a small angle with the horizontal, and is 7 feet in width. The crest and lower face were designed so as to give a true hydraulic curve to the water overflowing, and to attain this end the upper 15 feet of the face

was built with a batter of 1 to 1 so as to allow an air space under the water. The theory of the design is that air will enter this space under the water from the ends of the dam, and that enough will be carried down with the water to form an air cushion. With from 2 feet to 3 feet of water flowing over the dam, a very smooth surface is presented. Below the forty-five-degree batter the downstream

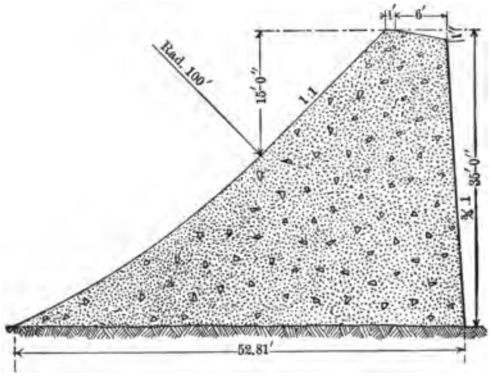



FIG. 145.—CROSS-SECTION OF DAM.

face has a radius of 100 feet. The upstream face has a batter of ¾ inch to the foot.

*Headworks.*—The head or diversion works of the gravity conduit consist of an enlarged or widened section of the intake tunnel with controlling gates operated by means of hydraulic cylinders. In order to prevent contraction as the water enters and to afford sufficient screen area to admit the water, the tunnel is widened out at the entrance to 16 feet 6 inches. The screens or grizzlies are made of slanting bars and extend both in front and on the side of the controlling gates. The bars are ½ inch × 3 inches and are spaced on edge, 3 inches between centres, by means of 2¼-inch thimbles, the thimble rods being 4 feet apart. The screen is 20 feet long on the slant and 8 feet high and is supported on 4-inch cast-iron pillars.

Behind the screen and just above the gate is a 10-foot platform on to which can be raked any detritus caught by the screen.

The grade at the entrance of the diverting tunnel is increased above the normal grade so as to accelerate the water from its state of rest above the intake to normal velocity in the tunnel below.

Another important feature of the headworks is the drainage or sluicing tunnel, 365 feet in length, that is driven through bed-rock below the intake at the south end of the dam, penetrating to the bottom of the reservoir above the diverting dam. A heavy grizzly, built of 70-pound T-rails, protects the entrance of this tunnel, and behind are two gates operated by hydraulic cylinders, by means of which the tunnel can be closed or opened as desired. The drainage tunnel was first used to divert the water from above the site of the dam during its construction to the river at a point some distance below the headworks. Its permanent purpose will be to sluice out, at such intervals as may be necessary, any silt accumulating in the reservoir above the dam. The gates of this drainage tunnel are constructed for operating under a pressure corresponding to from 35 feet to 45 feet, depending on the quantity of water flowing over the dam, the hydraulic cylinders for the gates being designed to move them under a head of 20 feet of water over the dam, should a flood of this magnitude ever occur.

Each of the gate openings is 8 feet 10¼ inches high and 3 feet 8 inches wide, the side frames being of cast iron, and the sill a 10-inch × 10¾-inch redwood timber. The gates are built of 5-16-inch steel plate and 6-inch 15-pound I-beams, the sides being formed of 12-inch I-beams. There are two cast-iron hydraulic cylinders installed in each gate. The set for the east gate is mounted on top of the concrete operating shaft, the west set being placed directly below, as there was not sufficient lateral space to place them both on the same level. The lower cylinders are placed 38 feet 8 inches above the sill of the gate, and operate their gate by lifting rods 26 feet long. The upper cylinders operate their gate by means of 40-foot rods. These lifting rods are 4½ inches in diameter, and are made of wrought iron encased in brass tubing to prevent rusting. The gates are guided at each side by four bronze rollers 3 inches in diameter. In order to equalize the pull of the two cylinders on each

gate there are installed two racks 10 feet long and 6 inches wide into which mesh two 12-inch pinions mounted on the top of the gate.

The gates for the intake tunnel are similarly constructed. The hydraulic cylinders, both for the intake gates and the sluice gates in the drainage tunnel, are operated by means of oil pressure supplied by gravity from a tank on the bank. The oil discharged from the cylinders is pumped up to this tank by a triplex pump, electrically driven, a sufficiently powerful hand pump being installed for emergency use.

*Tunnels.*—The hydraulic conduit of the Kern River plant is noteworthy by reason of its being the most permanent construction of its character in the country. The Edison Electric Company after its 14 years' practical experience with the construction and operation of hydro-electric power plants, has profited by the knowledge gained of the different forms of conduit used, such as timber flumes, earthen ditches, concrete-lined ditches, cement pipe and tunnels, and for its Kern River work determined that the most efficient, and, in the long run, economical construction would be a system of concrete-lined tunnels. The expense of driving the tunnels was a large item, but it was warranted in this instance because of the large quantity of water handled and by reason of its permanency and the fact that it will be subject to practically no depreciation losses and but little expense for maintenance. Another important feature of the tunnel construction is that there will be practically no evaporation loss from the conduit. As the evaporation from the natural stream of the Kern River is estimated to be from 15 to 20 per cent when the water is low during the summer months, this factor will be an important one during periods of minimum flow. Another advantage of the closed conduit is that no leaves, sticks, or other débris can enter the water after it leaves the headworks.

Between the intake and the forebay there are 19 tunnels forming approximately eight miles of gravity conduit. The number and length of these tunnels are given in the following table:

TUNNELS, KERN RIVER NO. 1 POWER PLANT.

| No. of Tunnel. | Length in Feet. |
|---|---|
| 1 | 595.0 |
| 2 | 3,136.6 |
| 3 | 4,049.4 |
| 4 | 496.3 |
| 5 | 1,522.3 |
| 6 | 1,805.1 |
| 7 | 874.0 |
| 8 | 3,815.8 |
| 9 | 2,049.7 |
| 10 | 3,010.8 |
| 11 | 2,587.0 |
| 12 | 2,169.9 |
| 13 | 2,335.3 |
| 14 | 4,373.7 |
| 15 | 3,767.5 |
| 16 | 1,498.4 |
| 17 | 1,898.2 |
| 18 | 2,131.5 |
| 19 | 794.0 |
| Total | 42,910.5 |

The tunnels are numbered from the intake down, Tunnel No. 1 being the intake tunnel, the entrance to which has already been described.

The tunnels were excavated in the rough to be 9 feet in width and 7½ feet from the bottom to the spring line of the arch, and 9 feet in height in the centre. Afterward they were lined with concrete 6 inches to 10 inches thick on each side and the floor paved with 3 inches of concrete, the net section thus obtained being 8 feet in width by 7 feet in height. The entire surface of the side and floor was covered with a cement-mortar-plaster ¼ inch thick, composed of one part of cement to two parts of sand. At the corners of the walls and floor a curve with a 3-inch radius was formed in order to prevent wear at that point and also to smooth up the flow of water.

The section of tunnel adopted is not the most favorable to give the highest velocity on a minimum slope, but is the most advantageous for the purpose, as by making a wider tunnel greater difficulties would have been encountered with the roof of the tunnel where it passed through loose or shattered formation. The grade

of the tunnels is 7.92 feet per mile, it being intended that the water should be carried at a depth of 6½ feet. The cross-sectional area of the stream is, therefore, 52 square feet, the wetted perimeter is 21 feet, and the mean hydraulic radius 2.5. Assuming the coefficient of roughness to be 0.012 in Kutter's formula, the conduit has a discharge capacity of approximately 470 cubic feet per second. Experiments made on other tunnels of the company indicated that the coefficient would be about the value stated for this particular conduit. Observations made during the first few days after the conduit was placed in service showed that the coefficient is even less than 0.012.

In places where the tunnels pass through seamy and shattered formation or "blocky" ground, they had to be arched overhead in order to support the roof, the concrete at the centre of the arch being from 12 inches to 18 inches thick. Less than 15 per cent. of the length of the tunnel required such overhead arching. Where this was necessary, it was placed by using a templet, with lagging overhead, the concrete being thrown back and tamped into place above the lagging. In excavating through this blocky ground, timbering was necessary, the standard bent formed of 6-inch × 8-inch sets, spaced 4 feet between centres and holding the rock back by 3-inch planks. In such sections the timbers were left in position and completely covered by concrete.

The concrete at the sides was tamped into place behind boards supported by vertical forms. Wherever large cavities had been blasted out in driving the tunnels, they were filled with back-fill of riprap, the interstices of which were filled with sand and gravel. The same method was pursued above the concrete in the arches. Consequently there are no cavities existing between the bedrock and the concrete lining in the tunnels.

In several places springs were encountered, and as the pressure that would be created by stopping them up might be disastrous to the tunnel lining, vents were installed through which the water can flow into the tunnel. These vents consist of sections of pipe from ¾ inch to 3 inches in diameter and 6 inches to 8

inches long, set in the floor or wall and left open at both ends. The water, being under higher pressure than that flowing in the tunnel, continues to flow into the tunnel and thus relieves it of any strain.

Portland cement was used throughout for the concrete, the mixture being in the proportion of 1, 3, and 5. For the sand and aggregate, the granite excavated from the tunnels was used. The rock was crushed to $1\frac{1}{2}$-inch and 2-inch size, and for the sand was crushed and rolled so as to pass through a 60 screen. As no adequate water supplies were available along the route of the conduit, the water necessary for mixing the concrete had to be pumped up from the river. The men worked on two nine-hour shifts, illumination being furnished by a construction power plant. A total of 110,000 feet of lumber was used for forms on the concrete work.

After the tunnels were completed, two two-wheeled hand carts with rubber-tired wheels were used for carrying cement and light tools for such finishing and repair work as was necessary. They were also brought into service in stringing the telephone line that is carried throughout the entire tunnel connecting the power-house with the diversion works at the dam. The two galvanized-iron wires of this telephone line are carried on inverted T-shaped brackets about 10 inches from the roof of the tunnel. The brackets are formed of $\frac{3}{4}$-inch pipe with porcelain insulators bolted on each end of the horizontal arm. The vertical pipe is secured in the holes of the rock or cement by wooden plugs.

*Timber Flumes.*—The tunnel work was planned so as to avoid, wherever possible, flumes for spanning the side ravines encountered along the line. However, in order to maintain a good alignment and make the line as short as possible, a few exceptions had to be made to this rule. Some of these side ravines leading down to the main canyon and crossing the line of the conduit were on such a flat slope that should the tunnel be constructed under the ravines, the necessary adits would have been very long. This not only would have increased the cost materially, but also would have

added to the length of the line and the time required to do the work. At such points where there was no danger from falling rocks the ravines were spanned with flumes. There are six of these flumes, the number and length of which are given in the following table:

FLUMES, KERN RIVER NO. 1 POWER PLANT.

| No. of Flume. | Length in Feet. |
|---|---|
| 1 | 1,029.6 |
| 2 | 129.8 |
| 3 (steel and concrete flume) | 49.9 |
| 4 | 73.5 |
| 5 | 167.5 |
| 6 | 70.4 |
| Total | 1,520.7 |

All are constructed of timber except No. 3, which is built of reinforced concrete with a steel frame.

Fig. 146 shows the method of constructing the timber flumes. They are placed on concrete foundations and are designed with a factor of safety sufficient to make their life from 30 to 40 years. The framework for supporting the flume box is of Oregon pine, being so designed and distributed that no part of the timber comes in contact with the earth or is exposed to the drip should the flume at any time spring a leak. In this way the life of the Oregon pine will be great.

The flume box is built up of 3-inch × 12-inch planks of redwood grown in swamp lands west of the Coast Range in Northern California. The grade of this lumber is perfectly clear, and its quality is such that its life should not be less than 40 years. The edges of all planks were bevelled so as to give $\frac{1}{4}$-inch opening on the inside of the joint, which is calked with ship chandler's oakum. The bottom seams were covered with hot asphaltum, and 1-inch × 6-inch redwood battens were nailed down over them.

On the sides of these flumes a specially designed batten is used. This is of 1-inch × 6-inch redwood, the upper half being cut away on a curve, permitting asphaltum to be poured between the batten and the side of the flume. At the corners of the flumes a quarter-round strip is nailed.

The design of the flume above described has been thoroughly tested; and even if it should remain dry for months in the hottest weather, its designers state that it may again be filled with water without having any perceptible leakage.

In some cases, where crossing streams that are apt to carry considerable water in winter, span flumes are constructed.

In connecting the wooden flume with the portal of a tunnel,

FIG. 146.—WOODEN FLUME.

use was made of a construction of a special nature, which offers two points of contact between the wood and the concrete, and a well between the two, from which the water may be pumped out, and any leaks repaired should these ever occur between the wood and the concrete.

*Steel-Concrete Flume.*—The flume between tunnels No. 6 and No. 7 across Laird Canyon is constructed of structural steel and concrete. The whole structure is carried on 15-inch steel I-beams set 8 feet 10 inches apart and supported by concrete piers. These

longitudinal girders carry 9-inch steel I-cross beams set 4 feet from centre to centre, and on them is erected a framework of structural steel for the sides and bottom of the flume. The layers of expanded metal (1½-inch and 3-inch mesh) are used in connection with this framework and, filled with concrete, form the plates enclosing the frame. This concrete construction is also reinforced on the floor by twisted ½-inch rods. The outside and inside of the flume were then plastered, making the thickness of the reinforced-concrete sides and bottom 4 inches.

This type of flume or conduit has proved a decided success, and while it cost more than a wooden flume, it has the advantage of being as permanent as the tunnels themselves.

*Concrete Conduits.*—In the lengths of tunnels and flumes enumerated forming the gravity conduit for Kern River No. 1 power plant, no account is taken of the concrete conduits which connect some of the tunnels and which also connect the tunnels with the flumes. There were places along the line where the tunnel emerged at the foot of a steep incline in such a manner that the flume if constructed on the grade would be threatened by landslides or bowlders rolling down the side of the mountain. These places were spanned by means of concrete conduits, the interior of which has the same cross-section and slope as the tunnels themselves. The walls are made heavy and reinforced with steel and an arch overhead, the arch being covered with a cushion of earthen material to receive the impact of anything rolling or sliding down the hill and passing over the conduit. There are eight of these conduits, the following table giving the length of each:

CONCRETE CONDUITS. KERN RIVER NO. 1.

| No. of Conduit. | Length in Feet. |
|---|---|
| 1 | 100.00 |
| 2 | 69.4 |
| 3 | 6.2 |
| 4 | 42.2 |
| 5 | 40.0 |
| 6 | 92.5 |
| 7 | 31.6 |
| 8 | 121.6 |

*Forebay.*—A terminal equalizing reservoir of some size at the end of the gravity conduit and feeding the pressure main would have been desirable in connection with the Kern River No. 1 project. However, the side of Mt. Breckenridge, where the lower end of Tunnel No. 19 emerges above the power-house, is approximately on a forty-five-degree slope, making it impossible to excavate any large area for a terminal reservoir or forebay. It was necessary, however, to have a small basin for regulating the flow into the force main, and for this purpose a chamber 30 feet × 42 feet was excavated to a depth of about 8 feet below the grade of the supply tunnel. Inside of this and over the mouth of the force main were erected controlling gates and screens through which the water passes into the force main.

The walls of the forebay were made of concrete in the form of retaining walls where they were enclosed in the excavation, and on the lower side where they were unsupported they were made sufficiently heavy to withstand the pressure of the water on the inside of the forebay. As the formation where the structure is located is somewhat shattered, the concrete work was heavily reinforced and the floor was paved with 3 feet of concrete. In the rear these walls were extended up to a considerable height to prevent material caving from the mountain above from dropping into the forebay.

On one side is a spillway 9 feet above the floor of the forebay, and consisting of five 82-inch openings over which the water flows into the waste flume when it is desired to divert part or all of the tunnel flow from the pressure main. The height of this spillway can be controlled by means of flash-boards which may be inserted and removed as required, according to the quantity of water carried through the tunnels. The extreme height of the spillway is 3 feet. A 24-inch gate valve is set at each end of the spillway for sluicing into the waste flume.

The force main starts from the bottom of the forebay, thus making it possible to have the water enter it from opposite directions. This construction tends to prevent the formation of eddies or a whirlpool at the entrance.

The controlling gates have an opening 6 feet 2 inches high and 10 feet wide, and are built up of 4-inch × 12-inch timbers on two vertical 6-inch steel I-beams. They are raised by means of hand-operated gearing through four sets of gears working into two racks (7 inches wide and 3-inch pitch) mounted on the front of each gate. Behind the gates and inclined upward toward each other are two heavy trash-racks. These are formed of 3½-inch × ½-inch iron straps, spaced 3-inch centres by thimbles of 2½-inch wrought-iron pipe, the rows of thimbles being set 1 foot apart. Each screen is 11 feet 6 inches long and is set on an angle with its top supported by a 4-inch steel I-beam. These two beams are set 3½ feet apart, the space between forming a walk.

*Waste Flume.*—The forebay is constructed so that when the water is diverted from the force main it passes over the spillway automatically into the waste conduit extending down the mountain-side to the river. This conduit is of concrete at the upper end, where it is on comparatively flat grade, the section being 8 feet wide and 8 feet 6 inches high. The water is discharged into a redwood flume 20 feet wide, that carries it down the steep slope of the hill. As the slope is about forty-five degrees, no material except soft wood would stand the wear due to the high velocity. The spillway flume is 1,200 feet long and it discharges into the Kern River about 600 feet above the power station.

The flume rests on 4-inch × 6-inch stringers bolted to 3-inch × 3-inch × ⅜-inch anchor plates embedded in concrete footings. These footings are spaced 8 feet apart and are securely set, although they are not carried down to bedrock in all cases. The cross-beams of the flume are 4 inch × 6 inch timbers, 26 feet 6 inches long. The side posts are 4 inches square and are carried up 3 feet 3 inches, being secured at the bottom by angle plates. They are set 4 feet centre to centre, and are angle-braced by 4-inch × 4-inch pieces fastened at both ends by ½-inch bolts. For lining the flume 2-inch × 12-inch redwood planks were used, the joints in the floor being calked and covered with 1-inch × 6-inch battens. Quarter rounds were nailed in the corners as in the other flumes. The

side lining, which is carried up 3 feet high, is battened and calked in the same manner as already described for the smaller flumes.

*Pressure Main.*—The greatest innovation in the entire Kern River No. 1 plant is the pressure main, the construction of which has been along new lines and in decided contradistinction to the customary practice of laying a steel pipe on the surface of the mountain slope or merely burying it sufficiently to cover it for protection against freezing or expansion and contraction such as might be caused by a wide range of temperature changes. The pressure main constructed on Kern River consists of a tunnel approximately 1,700 feet long driven through the mountain on an incline, and lined with steel varying in thickness from 3-16-inch to 1½-inch. This tunnel begins at the bottom of the forebay, passes down at an angle of approximately forty-five degrees, and, turning into a horizontal section, emerges at the lower end on a level with the floor of the power station. There are three vertical curves in the tunnel. The upper one forms an angle of seven degrees 260 feet from the forebay floor. The second curve, 32.5 feet lower down, has an angle of five degrees and turns the pipe into a grade of 84.93 per cent. on which it is carried 994.24 feet to vertical curve No. 3. This latter curve has an angle of forty degrees and from its lower end the pipe continues along on a horizontal grade to the power-house, the total length of the main being 1,697 feet.

The pressure main is finished to give it an inside diameter of 7 feet 6 inches. At the top a taper 20 feet long and 10 feet in diameter at the forebay entrance terminates in the regular 7½-foot diameter of the completed tunnel tube. This diameter is maintained throughout the inclined tunnel, and on the horizontal beyond vertical curve No. 3 for a distance of 167.39 feet. At this point, 1,454.44 feet from the forebay, the force main emerges from the solid rock and is carried to the portal, a distance of 243 feet through a detrital deposit lying between the mountain and the power-house site. Where the tunnel emerges from the solid rock a 20-foot taper was installed, reducing the diameter of the main from 7½ feet to

$5\frac{1}{4}$ feet, at which diameter the pipe is carried to the branch piping at the power-house.

The inclined part of the pressure main and the portion of the horizontal section that passes through solid rock were finished by installing a steel lining built up of plates 3-16-inch thick for the incline and $\frac{3}{8}$ inch thick for the horizontal, riveted together to form a cylindrical pipe $7\frac{1}{2}$ feet internal diameter. The tunnel itself was driven in approximately circular form and 9 feet in diameter. The steel pipe was centred in the tunnel, being installed in 10-foot sections, and the space between the outside of the steel lining and the bedrock was thoroughly filled with a mixture of concrete, consisting of three parts sand, three parts crushed rock, and one part Portland cement. The work of installing this lining was begun at the lower end in the horizontal section where the pipe is tapered down to the diameter of 5.25 feet. At this point the 20-foot taper already mentioned was placed, it consisting of $1\frac{3}{8}$-inch steel plate riveted together with butt straps. The taper was placed back in the solid rock, and around it was constructed a heavy bulkhead of concrete which was anchored into the bedrock by means of steel rods driven into the sides.

From this point the installation of the light steel lining with concrete back-fill, progressed from the bottom to the top of the tunnel, terminating at the reinforced concrete taper that connects with the floor and the forebay. The rock formation through which the force-main tunnel was driven is not of the best kind, being very much fractured and broken. It was necessary to timber the greater part of the shaft or incline when it was excavated, and these timbers had to be removed before the steel lining was installed. The timbers were removed ahead of the steelwork, the bedrock cleaned off, and the concrete tamped into place without difficulty. At a point about 120 feet below the top the men in charge removed some timbers without bracing the sets above. This precipitated a cave-in of the shaft, and several men lost their lives, one man being imprisoned for two weeks, after which time he was rescued in good condition. In retimbering the

caved portion, octagon steel sets of 7-inch, 15-pound I-beams were used. These sets were left in place when the concrete was put behind the steel lining. The lower end of the pressure main, from the taper reducing the diameter to 5½ feet in diameter, was made of 1⅜-inch steel plate, or sufficiently heavy to withstand the static pressure without any external support. No concrete was placed around this pipe, and the tunnel was merely left in its original condition with the timber sets to support the ground overhead.

At a point 215 feet above the power-house a manhole was placed in the inclined tunnel for convenience in inspecting and for use in case any repair work is necessary. The regular 3-16-inch steel lining was replaced at this point by a section of 1½-inch pipe 30 feet long.

The steel pipe was shipped to Camp No. 1 at the power-house from San Francisco in 5-foot lengths, five sections being nested together for shipment. The outside section was riveted complete on its two longitudinal seams, but the four inner sections were riveted on one seam only, so as to allow for the nesting. At the camp the pipe was riveted into 10-foot lengths and hoisted by means of an aërial tram to the forebay site at the upper end of the pressure tunnel. There the sections were secured to a dolly car, and lowered by means of a hoist to the point where they were riveted together. The car consisted of a truck at each end of the pipe section, the latter being hung from two timbers that passed through the pipe and rested on the axles of the trucks.

All the piping in the pressure tunnel, which is constructed of steel plates of ½-inch thickness and under, is made up with standard lap joints double riveted on the longitudinal seams and single riveted on round seams. All pipe on the work over ½ inch in thickness is made up of butt-strapped joints throughout, with triple riveting on each side of the longitudinal seams and double riveting on each side of the round seams.

After the steel lining was completed, an inspection of it revealed the fact that there were several places along the bottom of the pipe where voids had been formed in the concrete backing. These

voids, which were revealed by tapping, were caused mainly by the difficulty experienced in tamping the concrete thoroughly around the sections of steel lining. The steel sections were 10 feet in length, and in a few places where large irregular rock excavation occurred at the bottom of a section with only a 9-inch space at the top for handling the tamping bars, some voids were naturally formed because of the insufficient tamping.

Whenever a void occurred, a hole was drilled in the pipe and liquid cement was forced in until the hole was filled. The apparatus designed on the spot to accomplish this work was an ingenious one. A section of 3-inch steel tube 20 inches long was fitted at the bottom with a tap that would fit the hole drilled in the steel lining. Liquid cement was poured into the void by means of this pipe, which had a capacity of about an ordinary pail. When no more cement would run in, there was fitted in the pipe a screw with a plunger at the lower end and a crank on the outer end. By means of this device, the cement was forced into the void under pressure until it would hold no more. The pump was then removed and the hole in the lining stopped up by an ordinary flush pipe plug. There were 116 of these voids tapped and filled through the lining although only three of them were of large size. A number of the voids required only a pint of the liquid cement, the quantity used varying up to the largest, for which 10 buckets of the slush was necessary. The slush used was a liquid mixture of Portland cement and sand. The work was carried on from a dolly car fitted with bevelled wheels and lowered down from the top by a steel cable. About 15 days were necessary to complete this special work. After all the voids were filled the entire pipe was painted with asphaltum paint, the same dolly car being used for the purpose.

Although the design of the pressure main has been criticised by some, it is believed that the construction will stand criticism and will prove to be permanent, and for that reason economical. The steel lining has a low factor of safety, being only heavy enough to keep its form and to resist the internal pressure, while all external pressure is taken up by the concrete back-filling, which, backed

up by the rock itself, also resists the internal pressures. Being entirely under ground and some distance from the surface, no trouble will be experienced by reason of expansion and contraction due to temperature changes. The anchorage is the mountain itself so that no disastrous effects could result to the pressure main from any water ram that might be caused by improper handling of the water-wheels or gate valves.

*Branch Piping.*—At the lower end of the pressure main was constructed the header pipe, made of steel plates, varying in thickness from 1⅜ inches at the inner end to ¾ inch at the outer end, and consisting of the following specified lengths and diameters:

| Length. | Diameter. |
|---|---|
| 33.5 ft. | 4¾ ft. pipe. |
| 23.0 ft. | 4¼ ft. pipe. |
| 21.0 ft. | 3¾ ft. pipe. |
| 11.5 ft. | 3 ft. pipe. |
| 16.7 ft. | 2⅓ ft. pipe at the end. |

These diameters were graduated to maintain as nearly uniform velocity as possible after withdrawing the water for the various branches to supply the water-wheel units in the power-house. In reducing the force main at the branch pipes to meet the diameters given, the following taper pipes were employed:

| | |
|---|---|
| 1 taper | 7.5 ft. diameter to 5.25 ft. diameter, 20 ft. long. |
| 1 taper | 5.25 ft. diameter to 4.75 ft. diameter, 10 ft. long. |
| 1 taper | 4.75 ft. diameter to 4.25 ft. diameter, 10 ft. long. |
| 1 taper | 4.25 ft. diameter to 3.75 ft. diameter, 10 ft. long. |
| 1 taper | 3.75 ft. diameter to 3.00 ft. diameter, 10 ft. long. |
| 1 taper | 3.00 ft. diameter to 2.33 ft. diameter, 10 ft. long. |

The branches from the force main were taken off by means of a Y on the header pipe and laid out in curved form entering the power-house at right angles to the rear wall. There is one branch 28 inches inside diameter, 50 feet long, made of ¾-inch plate, for each of the eight water-wheels, and a 10-inch inside diameter branch pipe for each of the two exciters.

At the end of the last section of the force main is a 28-inch gate valve which discharges into the river.

In each of the branch pipes leading from the force main to the water-wheels are installed two 28-inch gate valves, one outside of the power-house and the other inside. The former is intended solely for the purpose of closing off the branch pipe in case of necessary repair to the gate or piping inside of the house. These outside gates are arranged only for hand drive, while those inside the power-house are equipped for operation either by hand or by electric motor as will be mentioned later.

*Power-House.*—The pressure tunnel emerges from the side of Mt. Breckenridge at an elevation above the sea of 1,061.95 feet. Directly in front of this point and slightly upstream there was a bowlder-covered wash protected by a bend of the river and bordered by a large mass of bedrock standing at the edge of the main channel of the river. This space was chosen as the power-house site. The intake of the Power, Transit and Light Company, of Bakersfield, is directly across the stream, and it is necessary to discharge the water from the wheels in such a direction and at such an elevation that it will flow by gravity into their intake.

The Kern River is subject at times to very considerable floods, and the elevation of the header pipe and consequently of the water-wheels was made sufficiently high to permit of running the units even when the stream is at its maximum flood.

The foundations were started on bedrock and cemented bowlers low enough to avoid any possibility of the power-house being undercut by floods, and the walls were constructed in such a manner that no important machinery rested on floors placed on back-fill. All spaces between these walls, except those which could not be utilized on account of their falling so low as to be subject to flood, were filled in with compact back-fill from other portions of the work.

The available area was so crowded that it was necessary to make a deep excavation in the hillside to accommodate the inner or eastern end of the building. The débris from this cut and from the tail-races was wasted on the south side of the building as a dump upon which the header and branch piping from the pressure main were placed. On the north side of the station the spoil bank

filled in a triangular area of the flat wash, raising its entire area above maximum high water and producing a bulkhead which will protect the power-house against any possible flood.

The foundations proper are of monolithic concrete. The rock and part of the sand for the aggregate were secured by crushing granite bowlders excavated from the site, as well as a large amount of rock which was lying on the pressure-tunnel dump. Additional sand was secured for a time from various small bars in the river

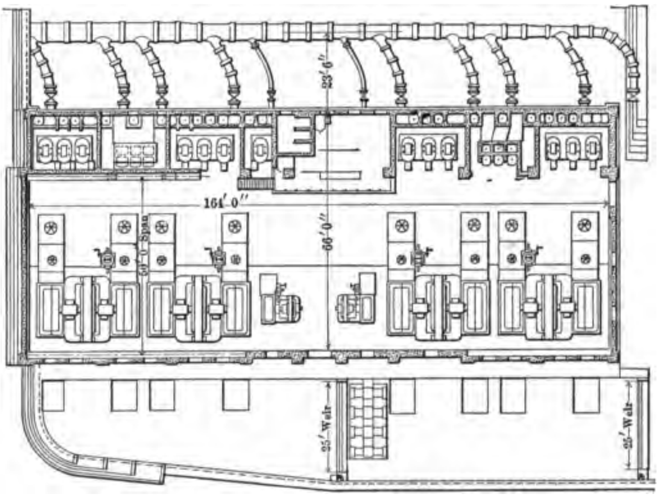



FIG. 147.—PLAN OF POWER STATION.

adjacent to the power-house. These were, however, covered by high water early in the year, and after that time all necessary make-up sand was hauled from the mouth of the canyon, about two and one-half miles distant.

The upper part of the machine foundations carries a small amount of reinforcement. The large block of masonry back of each water-wheel deflector is heavily reinforced and tied into the main foundation blocks. The crane-rail arches for the interior wall are reinforced concrete beams, with the exception of the long span above the switchboard, which contains an I-beam girder.

By reason of the length of the building and the importance of the work, no account was taken in its construction of the additional strength resulting from the continuity of the beams, the bridging effect of the crane rail, nor its cushioning timbers, nor was any allowance made for the 12-inch curtain walls which fill in below this beam in places. The north wall, however, is a 12-inch curtain wall reinforced with heavy pilasters, and contains only sufficient reinforcement to render it reasonably secure against shock and vibration. The south wall of the building is of a cellular construction for about two-thirds of its height, in order to provide wiring ducts for the 60,000-volt connections. This wall also contains only nominal reinforcement. Between this wall and the interior crane wall, a space 15 feet wide, a series of transverse partitions break up the area into transformer-, switch-, and switchboard-rooms. The transformer-rooms are open up to the crane beam to permit of wheeling the transformers out under the main crane. The crane-rail columns are not highly stressed and have no hooping whatever. A 50-ton electric travelling crane, with a 50-foot span, serves the entire machine-room.

The switchboard space contains a deck 8 feet 6 inches above the floor level, upon which the control board is mounted.

The roof of the building is of galvanized iron laid on wooden purlins, which are placed on steel roof trusses of 52-feet 1-inch clear span. The internal length of the machine-room is 164 feet, and its clear width is 66 feet 6 inches. The generating units are located along the north side of the station, 78 feet from the centre of the pressure header.

*Other Hydraulic Features.*—Dead water leaving the water-wheels flows down the floor of the wheel-race into the main tail-race. When the nozzles are deflected the water is diverted past the buckets onto a pair of heavy metal deflector plates.

These deflector plates are 7 feet wide, and the lower one projects out into the tail-race 8 feet.

The speed regulation of the water-wheels is effected by a governor which deflects the jets of the two nozzles. The needles are ad-

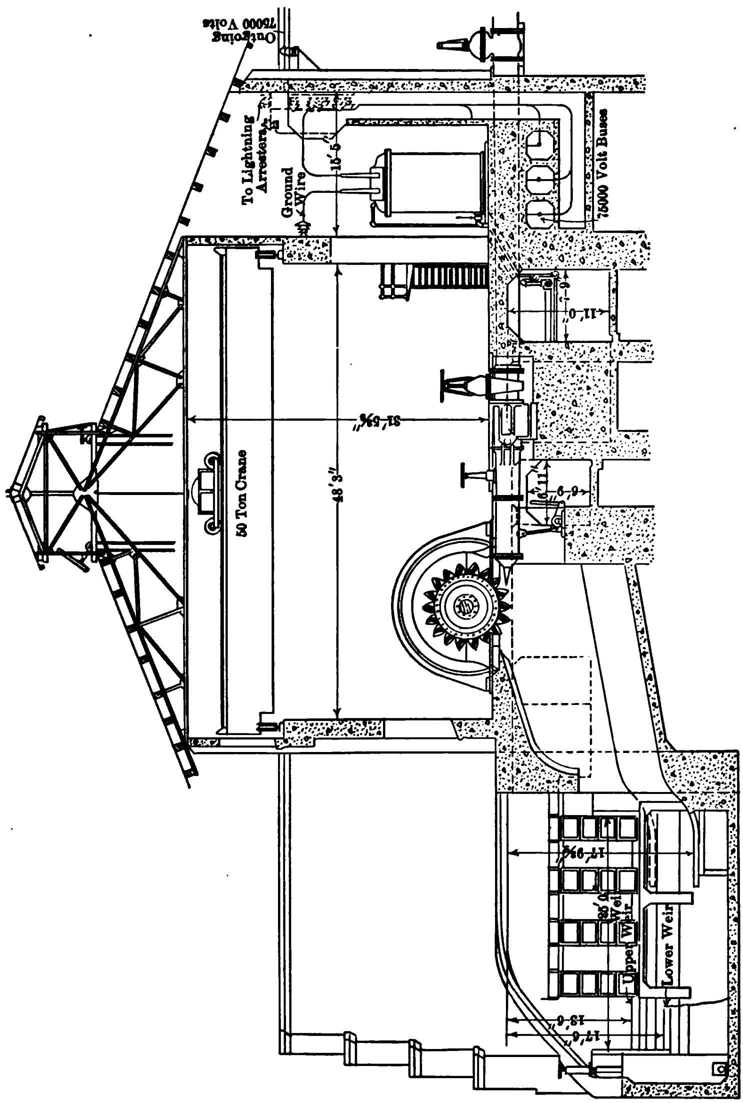



FIG. 148.—CROSS-SECTION THROUGH POWER-HOUSE.

justed by hand and are usually set to that maximum size of jet which will be sufficient to develop the maximum peak load expected for that period of setting on the needles. In other words, there is always a maximum amount of water leaving the nozzles. The governor adjusts the deflecting nozzles in such a way that only as much water is directed upon the buckets as is needed for the load for the time being; the balance discharges below the buckets into the tail-race. It is evident that at times when all load is thrown off the wheels, the governor will deflect the jets entirely. Each jet has a maximum diameter of $7\frac{3}{8}$ inches, and leaves the nozzle tip at a velocity exceeding 225 feet per second. It was, therefore, necessary to provide means for receiving the tremendous force and for deflecting the jet into the tail-race.

The arrangement designed consists of the pair of heavy deflector plates onto which the jet is diverted, as noted above. The upper of these plates consists of a channel heavily ribbed and bolted to the concrete foundation. The channel at its upper end is slightly more inclined than the deflected jet. Thus the jet strikes the bottom of the channel under a small angle, and therefore tends to spread and fill the section of channel. The channel gradually widens, and consequently the jet is offered a larger resistance area. The lower part of the channel is curved, and at its end the jet discharges almost perpendicularly downward. The bottom plate is S-shaped, its upper end being flush with the bottom of the wheel-pit, the lower end practically level. The jet strikes the bottom plate almost in the turn of the "S" and under a small angle. Thus the jet is again forced to spread and follow the base of the bottom plate. In due consideration of the unavoidable wear and tear of these deflectors, they are lined with removable steel plates wherever the surfaces are exposed to the flow of the deflected jet, being held in position by lag screws.

The wheel-races are lined with steel on both sides and fitted with steel plates just back of the nozzle tips to keep the splash water out of the shaft alley.

The tail-race is 29 feet wide and extends the length of the power-

house. It is fitted with two 25-foot steel-plate weirs, the lower weir at the end of the tail-race being 4 feet below the level of the upper weir, which has its crest 13 feet 6 inches below the line of the nozzles.

The water-wheel branch pipes enter the power-house at the south side and, after passing across under the transformer-room and before joining the nozzle bases, connect to 28-inch cast-steel gate valves. These valves are of a special design, and each is operated from the control switchboard by a 1.2-H.P., 120-volt motor. It requires 7½ minutes to open or close a valve by means of the motor. Each gate valve is equipped with a 4-inch by-pass.

In the machine-room of the power-house is installed a Dibble reservoir gauge equipped with an indicating dial and a registering chart for measurements of the water in the forebay.

*Construction Plant.*—A construction plant generating 300 K.W. at normal rating was installed for furnishing the energy used in driving tunnels, mixing concrete, transporting materials, etc. This construction plant was located at Frenchtown, or Camp 5, power being developed by means of a flume about 800 feet in length which supplies water under 40-foot head to two McCormick reaction turbines each operating one 150-K.W., 2,300-volt generator. This plant furnished all the energy required while the work was in progress, being frequently and for long periods operated at 50 per cent. overload, and was abandoned only after the completion of the main plant. From the construction plant, energy was transmitted at 10,000 volts to all parts of the work over a temporary transmission line.

*Methods of Construction.*—It can be said that the methods of construction employed were among the most modern known to engineering practice. For constructing the tunnels, air compressors were driven by motors using electric energy transmitted from the construction plant, as already stated, the air being piped into the various tunnels where it was used for operating pneumatic drills. Ventilating blowers for supplying fresh air at the face of the tunnels and for removing the fumes after a blast were operated by electric motors. In the construction of the diverting dam, a

complete system of cableways was installed, by means of which material was transported and placed in position in the dam. In the construction of the power-house, the handling of materials as well as the crushing of rock and mixing of concrete was carried on by means of the most modern equipment operated by electric motors.

*Water-Wheels.*—The water-wheels selected for the Kern River No. 1 plant are of the impulse or tangential type. There are eight wheels installed, two for each of the four generators. The two wheels for each unit are overhung, one on each end of the generator shaft, the unit being of the two-bearing type. The water is projected onto the buckets of the wheels through deflecting nozzles of the needle-valve type mounted at the end of the 28-inch branch pipes. By means of these deflecting nozzles and needle valves the discharge from the tip of each nozzle can be accurately regulated without altering the form of the jet to any appreciable extent.

The wheels are designed to run at 250 r.p.m., and the two wheels on each unit are guaranteed to deliver a total of 10,750 H.P. to the generator shaft. Regulation of the wheels is obtained by means of self-contained oil-actuated hydraulic governors working under 125 pounds pressure. The governors act on the nozzles and deflect the stream off from or onto the buckets of the wheel as the load on the generator is decreased or increased. The governor for each unit is placed midway between the two nozzles and is connected to a common rock shaft which, in turn, actuates the two nozzles by means of rocker arms. These shafts are below the main floor and are accessible through a longitudinal shaft alley or tunnel 5 feet wide and having a clear head room of 6 feet 9 inches.

The nozzles are equipped with needles for adjusting the size of the stream by hand. For convenience in construction and to permit of balancing them for back-thrust, the needles are straight-backed, running through a guide sleeve of their full diameter into a balancing chamber supplied with water from the pressure side. The needle then reduces to a stem and passes through a second

stuffing box, beyond which the control links are attached. The needles are torpedo-shaped, being 8 feet long, 12 inches in diameter at their full diameter, and 8½ inches in diameter at the stem. The tip is about 25 inches long and is carried down to a blunt point on straight lines. The needle is operated by means of a hand wheel on the main floor, the wheel stand also supporting a pressure gauge connecting with the nozzle, and the two pipes connecting the two sides of the nozzle body with the balancing chamber of the needle. Each nozzle throws a jet 7⅝ inches in diameter at full opening.

The nozzle casting is bifurcated, the design being adopted to permit of bringing the needle stem out without offsetting the nozzle, as is done in other types of deflecting needle nozzles. The strain on the ball-joint bearings is equalized in this construction. The nozzle is a heavy steel casting, the Y portion weighing 15 tons. A counterbalancing plunger is located at the lower end of each operating lever below the nozzle. The needle stems and part of the tips are of steel. Some cast-iron tips have, however, been supplied, and it is expected that they will wear as satisfactorily as the steel ones.

Each of the revolving elements of the wheels is 9 feet 8 inches in diameter, and consists of a cast-steel rim to which are bolted 18 bronze buckets. These buckets are 27½ inches wide and are not radically different in form from modern buckets used elsewhere on the Pacific Coast, being in general of an ellipsoidal shape, with a straight front wall and a dividing wedge that dips down toward the front of the bucket.

The housings of the wheels are of cast iron with graceful lines, and where the shaft enters are fitted with compound baffle plates or water guards to prevent water escaping from the housing.

The combined moment of inertia of the revolving element in the two water-wheels and generator of each unit is $W R^2 = 1,800,000$ pounds-feet, by means of which regulation at 100 per cent. load variation is obtained within less than 8 per cent. when the units are carrying 50 per cent. overload, and within less than 5⅓ per cent. variation of speed when running at normal load. The guarantee

requires that the water-wheel proper shall develop an efficiency at rated load of 82½ per cent., which guarantee is to be substantiated by tests conducted by the company.

*Governors.*—When the governor arrangement for the water-wheels was designed, the leading idea was to have each turbine with its respective governor form an independent unit. Although the available operating water pressure of 370 pounds from the force main is ample to operate governors, it was preferred to substitute oil pressure. This precaution is fully justified, as long years of experience in operating hydraulic governors has proven that the safety is rather questionable, and the wear and tear of the parts of regulating valves causes a constant expense for repairing and replacing parts, which necessitates shutting down the respective units. It was also deemed preferable not to feed the governors with oil pressure from a central system, but to make each governor absolutely self-contained. The oil pressure used is 125 pounds per square inch.

Special attention was paid to the safe operation of the units, eliminating from the beginning any tendency to run away. For this purpose, the arrangement of the generator, as well as the exciter governor, was made in such a manner that the jets will be automatically deflected from the buckets whenever the oil pressure in the governor should fail.

The weight of the two deflecting nozzles for each unit is partly carried by a hydraulic balancing piston placed midway between the nozzles, which receives water pressure directly from the force main. The governor arm connects by means of a link to a common rock shaft, which in turn actuates the two nozzles by means of rocker arms. The design of the connection is such that as soon as the oil pressure in the governor fails, the nozzle will lower on account of the unbalanced weight, and thus deflect the jet from the buckets. The same result is accomplished with the deflecting hood of the exciter wheels, which is connected to a hydraulic water piston, tending always to insert the hood and thus deflect the jet.

Each governor is driven by a Morse silent-running chain from

its wheel shaft. The connections between the operating pistons and the deflecting nozzles or hoods consist of levers, pins, links, and shafts. The use of gears or racks has been avoided, thereby preventing jars which would result in lost motion and wear and tear.

Attention may be also called to the fact that all constituent parts, as well as all accessories, are attached or combined with one main casing, the advantage being that each governor can be assembled and thoroughly tested in the factory, and shipped completely assembled to its final destination. The main casing contains the main operating cylinder with piston and mechanical hand-regulating device. The oil pump is attached to the casing and immersed in the oil reservoir. It is of the rotary type, having no valves, which are often the cause of failure of oil pressure. The main pump shaft also carries the bevel gear which drives the fly-balls operating the pilot valve over the regulating lever. The pilot valve is self-contained between opposing pressures, and any reaction upon the fly-balls is eliminated. It is evident that this is a principal condition for exact regulation. The pilot valve distributes the oil pressure in the regulating cylinder. The motion of the regulating piston is reversedly transmitted to the regulating valve by means of a combined compensation. The leverage of this compensation is adjustable, so that the governor may be set for any load-speed characteristic, from 16 per cent. to absolutely constant speed.

The governors are equipped with four regulating devices which can be used at any time: 1. Mechanical hand regulation (without oil pressure). 2. Automatic regulation with fly-balls. 3. Hand regulation with oil pressure (fly-balls disconnected by a clutch coupling inserted between pump shaft and fly-ball shaft). 4. Hand regulation with oil pressure and electric motor operated from the switchboard. (Synchronizing attachment.)

The exciter governors are of similar design, except that they are not provided for electric hand regulation.

There are two exciter units, each being of the two-bearing type, with an impulse water-wheel on one end and a heavy fly-wheel designed to give the unit close regulation on the other end

of the shaft. The exciter wheels are operated from stationary needle nozzles, the needles being of the same straight form used on the main wheels. Regulation is obtained by oil governors which operate stream deflectors that are pulled up into the stream from below as the load on the unit decreases, thus deflecting a part or all of the stream into the tail-race. The exciter wheels are of a construction similar to the large wheels, having 20 bronze buckets $9\frac{3}{8}$ inches wide bolted to the rim of the runner.

*Generators.*—The main generators have a rated output of 5,000 K.W. each. The stationary armature is bar-wound for 2,300 volts, three-phase, 50 cycles. Each main unit is provided with two 16-inch × 48-inch babbitted bearings, each fitted with six oil rings. In the pedestals the oil is cooled by means of water coils. Each bearing also has in its lower portion a number of small openings which are connected to a triplex motor-driven pump, capable of circulating the lubricating oil under a pressure of 1,000 pounds to the square inch.

The generator shaft is flared out at each end to form a flange to which is bolted the wheel disk. The shaft is also enlarged at the centre to carry the cast-steel pole rim and spider. This latter is a single casting weighing twenty-six tons. The pole pieces are wedged to the exterior of this rim.

The exciter units are standard 225-K.W. direct-current machines, generating at 125 volts, flat compounded, running at 430 r.p.m., and have ordinary self-adjusting bearings. Sufficient space has been left between the two exciters to permit the installation of a large induction motor at some future time if it should be found necessary. This motor would be designed for good speed regulation and arranged so that it could be connected by means of a pair of clutches to either of the exciters.

*Output of the Plant.*—The normal rated output of the Kern River No. 1 power plant is 20,000 K.W. The machinery is tested to operate under 50 per cent. overload for peak load service, thus making the maximum capacity of the installation 30,000 K.W.

*Transformers.*—The station contains thirteen, 50-cycle, 1,667-

K.W., oil-filled, shell-type, oil-circulated, one-phase transformers in boiler-iron cases. These transformers are grouped in four banks of three each, with one spare, to receive power at 2,300 volts delta from the generators, and to supply it to the line at 75,000 volts Y. Taps are also provided for the intermediate voltages of 56,250 and 37,500.

These transformers, instead of having internal water-cooling coils, are so built that when the oil is supplied to them under a slight pressure it will automatically distribute itself throughout their windings and return itself by gravity to the waste pipe. The piping and connections for this circulation, which are placed in the basement of the power-house, consist of a 4-inch supply line, a 6-inch return line, and a 4-inch waste. These principal pipes are placed in a tunnel 7 feet 9 inches wide and 11 feet high, extending the length of the building.

The oil coming from the transformers enters a receiving drum from which it is drawn by two 5-inch centrifugal pumps, driven by 15-H.P., variable-speed, shunt-wound, direct-current motors. Either pump can supply oil to the entire equipment of transformers in an emergency. These pumps force the oil through a set of boiler-tube coolers set over the tail-race, consisting of a series of 2-inch pipe, 10 feet long, made up in four sections containing 1,008 tubes, and having a total area of 4,500 square feet. From these cooling-coils the oil returns to the pressure line, from which it is supplied to the transformers.

This system has been carefully laid out with strainers, by-passes, and other auxiliaries so that the entrance of any foreign substances into the oil will not cause trouble. As the system is under pressure from the time the oil enters the pump, any leakage will be outward and there will be no possibility of water leaking into the oil, as is the case where the water coils under pressure are placed in oil-filled transformers. The oil is specially refined. Another advantage of a system of this kind is that the cost of installation is somewhat less than for a similar installation using water-cooling.

Water for the cooling-sections is by-passed from one or both

of the exciter tail-races into a flume built across the top of the coolers.

*Electric Details of Station.*—The generator leads pass through ducts, under the station floor, to the generator switches, and from thence to the low-tension side of the transformer banks. The station is not equipped with a complete 2,300-volt bus-bar system. There are, however, motor-operated, oil tie switches placed between

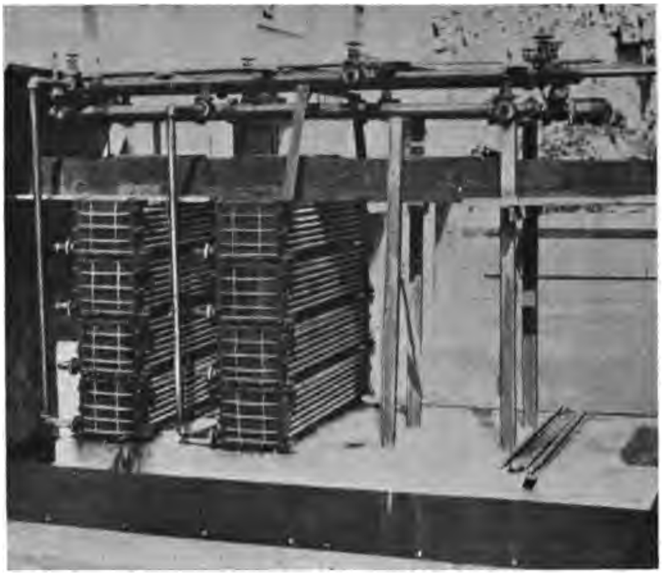


FIG. 149.—COOLING-COIL FOR CIRCULATING TRANSFORMER OIL.

adjacent machines and equipped with double-throw switches in such a manner that, in case of necessity, any generator can be transferred by means of this transfer line to any single transformer bank, or run in multiple with some other generator on a single transformer bank, or, if desired, the entire station can be tied together by means of this transfer bus and operated as a single unit.

The transformer banks connect on their high-tension side through knife-blade switches to a single bus-bar, which is sectioned

in the middle. The two outgoing transmission circuits are tapped off this bus-bar between adjacent transformer banks through motor-operated oil switches. These switches are remote-control, non-automatic. By use of them and the section oil switch, all high-tension power switching can be handled without the use of air-break switches. At the same time the investment for high-grade switching is reduced to a minimum. The 2,300-volt oil switches

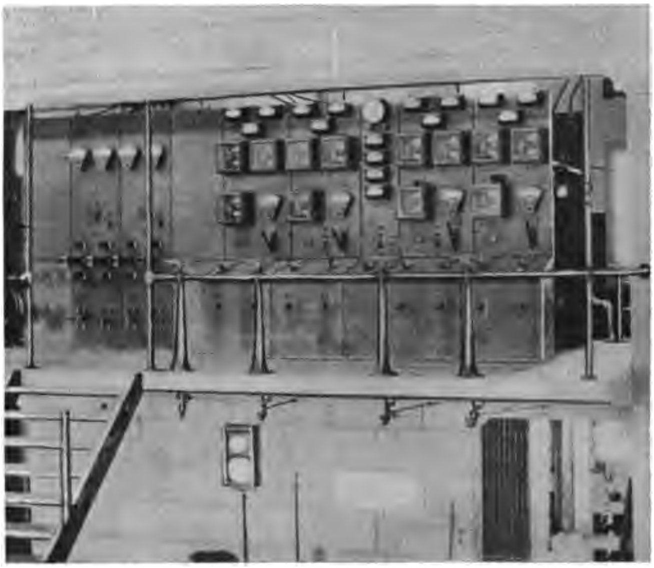


FIG. 150.—SWITCHBOARD.

are installed in cells with concrete barrier walls and tops. The disconnecting switches for them are also separated by barrier walls where possible. The 75,000-volt oil switches are not only installed in concrete cells in accordance with standard practice, but each of them is enclosed in a separate concrete room containing no additional apparatus except lightning arresters.

The control switchboard is mounted on a gallery overlooking the machine-room. It is built of black slate and is a combination

bench and panel board, consisting of nine divisions. The first panel on the left controls the station auxiliaries, the feeder for which is taken off the two centre sections of the 2,300-volt bus through solenoid-operated oil switches and then through two solenoid-operated oil switches to the panel.

The second and third panels are equipped for handling the exciter circuits, and each is provided with an ammeter, a voltmeter, and two single-pole, double-throw knife switches for connecting the exciter to either of the two exciter buses. The panel also has two double-pole, double-throw switches for connecting the exciter bus to the station lighting circuit and to the operating buses which

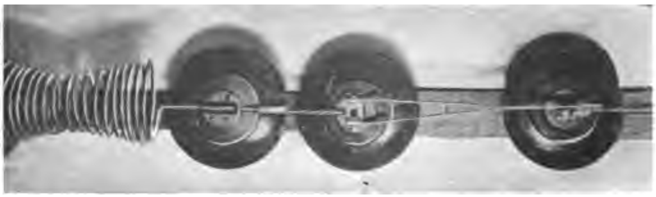


FIG. 151.—DISCONNECTING SWITCH AND CHOKE-COIL.

control the oil-switch motors, the lamps on the control board, and other auxiliaries.

Panel No. 4 is blank, while Nos. 5, 6, 8, and 9 are generator panels. Each of the latter is equipped with three Thomson ammeters, a field astatic ammeter, a curve-drawing ammeter, a curve-drawing voltmeter, and a curve-drawing wattmeter.

The seventh panel is the auxiliary feeder, bus-sectionalizing and station panel. It contains a synchronism indicator and two voltmeters on the synchronizing bus, an ammeter on the ground circuit, and an ammeter on the auxiliary feeders.

The bench of the switchboard has controlling switches with red and green signal lamps for each of the four generators, and there are also provided control switches for each of the two 2,300-volt feeder switches, for the switches on the 2,300-volt bus sections, and for the 75,000-volt outgoing line switches. The base of each

generator bench panel has one governor control switch and a double-pole, double-throw control switch for operating the two 28-inch valves on each water-wheel unit.

On the six-panel rear switchboard are mounted five polyphase watt-hour meters, break switches, and disconnecting switches on the field circuits. A curve-drawing, frequency-registering meter, driven by a $\frac{1}{4}$-H.P. motor, is also installed.

The high-tension wiring is run in 4-foot square ducts throughout, no open wiring being permitted except connections from transformers to the wall through their disconnecting switches, and from the lightning arrester disconnecting switches to the lightning-arrester banks.

The lightning arresters are of multiplex type, consisting of alternate carbon spark-gaps and resistances. The circuits are equipped with choke coils, consisting of 20 turns of hard-drawn copper. The lightning arresters are mounted in concrete-wall cells, and are so completely isolated from each other by the intervening main-line ducts that an arc starting on any single arrester could not by any possibility be transferred to a second bank.

The leads, after passing the choke coils and taps for the lightning arresters, pass out of the south wall of the building through rectangular openings located immediately below the eaves. To prevent the drip from the long run of roof from falling on the wires, a gutter extends for a few feet across the roof above each entrance. From the eaves of the building, the leads converge onto the first tower of the transmission line.

*Transmission Line—Route.*—From the power-house the transmission line runs, as near as may be in a straight line to the mouth of the Kern River Canyon, $2\frac{1}{2}$ miles distant, where it sweeps off to the left across the Cottonwood Hills, and then takes a due south course across the edge of the Bakersfield plains. The line then enters the mountainous section through Tejon Canyon, follows across the end of Castaic Lake, and crosses the Coast Range divide immediately above German Station.

This is the steepest portion of the transmission line, as the

drop from the top of the hill to the road below is over 1,000 feet in 3,500 feet. From here south the transmission line follows the waters of Piru Creek and its tributaries, the character of the country changing gradually from low, rounded hills with grassy slopes to

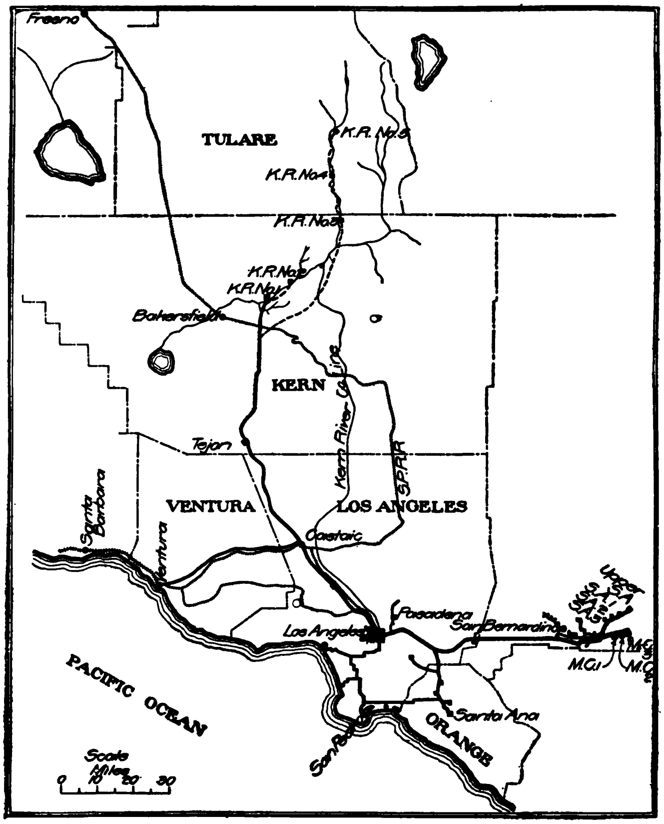



FIG. 152.—MAP OF TRANSMISSION LINE.

deep, narrow gorges walled with precipitous shale cliffs capped with sandstone ledges.

A section here of about 5 miles involved very difficult work. Heavy angles, both vertical and horizontal, were necessary in a district where no permanent wagon road could be maintained

and where the tower footings were mostly in loose shale. One U-bend of the river was crossed by means of a 2,250-foot span between the main supports, guided by an entirely unloaded tower at the bottom of the sag.

Leaving the Piru Canyon, the line passes in an almost straight line across about 15 miles of rocky land covered with scattered oaks and chaparral. After reaching the last crest of this district, the line falls away rapidly to the open country surrounding Newhall. Across this entire district it was necessary to construct a permanent wagon road to haul supplies and permit of patrolling the line during operation.

In the Newhall district, the line crosses the San Fernando Mountains directly west of the long tunnel on the Southern Pacific. Beyond this point it is in sight from the railroad track most of the way to Los Angeles, and throughout the greater portion of the route the line is erected in the open country, so that in case of necessity it can be repaired without excessive delay.

*Towers.*—The transmission line is carried on galvanized steel towers, there being 1,140 of these towers. Their heights range from 30 feet to 60 feet. They are uniformly constructed of galvanized angle iron, bolted with galvanized bolts and held in shape by means of tension rods. There are no compressive braces except one pair in the upper portions of the sides and between the cross-arms. The nine insulators are spaced on 6-foot centres, five on the upper arm and four on the lower, the arms consisting of 9-inch 13¼-pound channels.

All portions of the tower are figured to be safe under a wind pressure of 30 pounds per square foot on the tower and the wire of a 700-foot span. The towers will also withstand absolute failure of any single wire, even though none of the resulting strain is transmitted to adjacent wires.

Fig. 153 illustrates the construction of a standard 60-foot tower, which is 12 feet wide and 12 feet across at the base. The uprights are formed of 4-inch angles and the cross-braces of 2¾-inch, 3-inch, and 3½-inch angles, the diagonal rods being 11-16

inch and ⅝ inch in diameter. Four insulators for the telephone lines are mounted on the third cross-bar, 21 feet above the ground. Forty of the towers were made extra heavy for use at points where the line changed its direction.

The foot-plates of the towers are of cast iron, dipped in asphalt,

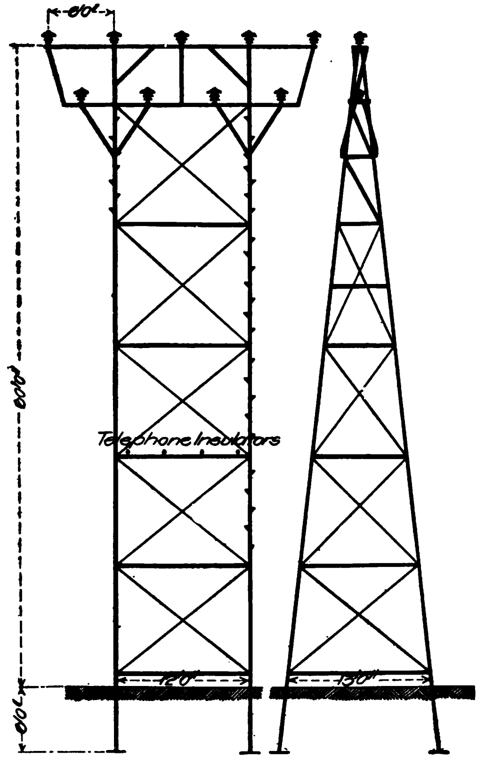



FIG. 153.—STANDARD 60-FOOT STEEL TOWER.

and 24 inches in diameter. They are attached at the bottom to 4× 4-inch foot posts, which are asphalted on top of the galvanizing. These posts are bolted as extensions to the corner posts of the tower, and set in the ground a depth of 6 feet. Tapered holes were dug for these foot-plates and the earth was tamped back on them very carefully. No concrete footings were used, except on

some special work in the city of Los Angeles, where a great many of the tower heights exceeded 60 feet. The tower parts were made as light as was consistent with rigid construction. Under the extreme conditions mentioned above, the factor of safety in any steel member is specified to be not less than 2½.

No cast iron was permitted in the construction, except in the foot-plates. All connections are made with malleable-iron castings with a factor of safety of 4. The insulator pins are of cast steel and were furnished as a part of the tower. They are secured to the tower by four bolts and are cemented into the insulators.

The towers were shipped from the factory knocked down, with their small parts boxed, and were hauled to their respective locations by wagon. They were assembled lying on the ground, and "kicked" into place by means of a gin pole. This method of erection was found to be very satisfactory for all sizes of towers, and only such towers as were located in rugged or inaccessible country were built up piece by piece.

In stringing out the wire, teams were used with usually four animals, although in limited spaces two horses on a tackle were substituted. Wherever possible, those wires which could be lifted onto the tower were strung out alongside and later on thrown into place.

*Line Construction.*—The transmission line is designed to consist of three circuits with the wiring spaced symmetrically on 6-foot centres. This wire is seven-strand, 4-0 hard-drawn copper, having an elastic limit exceeding 35,000 pounds total, and an ultimate strength of 62,400 pounds. About 2,500,000 pounds of cable were used on the line.

The wire was sampled and tested at the mill before being accepted. It was greased and shipped on reels containing usually two 4,000-foot lengths. Some wire was also purchased in shorter lengths for convenient use in the mountain section. No special difficulty was, however, experienced in handling full-length pieces even in the most rugged country.

The type of clamp used is shown in Fig. 154. It is 2 inches long,

and is constructed of three pieces, the inner piece being shaped to conform to the two wires. The tie wires passing around the neck of the insulator are of No. 1 copper strand. The four-bolt clamps are of brass, while the U-piece placed in the top of the insulator to prevent chafing is of No. 24 copper. The tie wires fail in test at about 4,000 pound. The clamps will withstand somewhat

FIG. 154.—DOUBLE INSULATOR SHOWING METHOD OF TYING.

more, and the construction could readily have been made much stronger at a slight additional expense if it had been considered desirable.

The insulators used are 18 inches in diameter, and the two lower petticoats are, respectively, 14 inches and 11 inches in diameter. Each assembled insulator weighs 50 pounds. The main contract, for 7,500 insulators, or over 90 per cent. of the total number, called for a glaze that would match the galvanized steel towers. The manufacturers were successful in producing an insulator with a light gray or slate-colored glaze which harmonizes very well with the hue of the towers. The resulting construction is comparatively inconspicuous on the transmission line, and the insulators, being of this neutral shade, do not afford as prominent a target for malicious marksmen as do those of the ordinary brown glaze.

The insulators were all carefully tested at the factory by one of the Edison Company's engineers. The specifications called

for a guaranty of a 100,000-volt test from the groove to the pin for half an hour under a precipitation of 1 inch in five minutes at an angle of thirty degrees from the vertical. The assembled insulator was required to withstand under a wet test a potential of 150,000

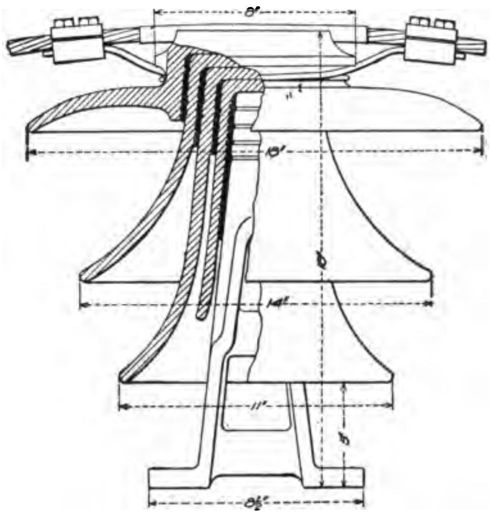


FIG. 155.—SECTION OF INSULATOR.

volts for 30 seconds, and the separate parts are guaranteed to withstand a voltage of 25 per cent. in excess of the normal proportion of over-voltage test.

The insulators are guaranteed to withstand a side strain of 4,000 pounds and actually fail at approximately 9,000 pounds. The wire has an ultimate strength of 61,300, but its elastic limit, as noted above, will not much exceed 35,000. The normal failing point of the ties, 4,000 pounds, is, therefore, sufficiently high for safe construction, while they are not so strong as to stand more than the wire or the insulators.

The transmission line, as stated elsewhere, is carried on spans as long as the character of the country would permit with towers not exceeding 60 feet in height. This maximum height was determined upon as being that which would give the lowest total

cost of construction. The sags for the different spans being determined and the telephone clearances from transmission wires being assumed at a minimum of 7 feet, it was necessary to determine the tower spacings with minimum safe ground clearances in the different portions of the line. In order to do this accurately, survey parties were sent over the entire line, taking tower locations, and determining all elevations so that they were able to plot a profile of the transmission system showing the elevation of each tower, the height of the intermediate elevations and the important topography of the country. The parties designated the height of the tower while in the field, making their profile as they went along, and checking the resulting line before leaving that section of the country.

A telephone circuit is carried the entire length of the transmission line, being supported on the towers about 20 feet above the ground. Between towers the wires are held up by wooden poles, two poles being necessary between towers for an average 700-foot span.

*Switching Stations.*—The transmission lines are carried through from one end to the other, with transpositions only at switching stations. There are at present only three such buildings, at Tejon, Castaic, and San Fernando, the latter two of which contain transformer substations.

The switching station proper is equipped with two sets of oil-break switches for each line and two sets of knife-blade disconnecting switches for each line. The oil switches are connected, one set after another, into a complete circle. After passing through the disconnecting switches, the incoming lines are tapped between alternate oil switches. From the vacant jumpers left after these lines have been tapped in, their corresponding outgoing circuits are taken, and, after passing through the disconnecting switches, leave the building on the opposite side.

The switching-station buildings are constructed of concrete in the most substantial manner. The circuits are isolated from each other by means of concrete barriers and floors. Individual

leads of the same circuit are, however, run in the same compartment. In spite of the large number of crossings called for by the wiring diagram, the dimensions of the building are not excessive. The Castaic substation is 66 feet long and 41 feet 6 inches wide, with a cross-partition wall forming the switch-room. 40 feet wide, and the transformer-room 26 feet wide. Provision has been made to connect horn lightning arresters to the circuits at these substations if it is found necessary after the line has been operated for some time.

The two transformer substations have in their switching-houses an arrangement identical with that in the other stations, except that openings were made in the west wall, through which leads were taken into the adjacent transformer-house. The two were built together under the same roof and with continuous side walls so that there is on the exterior little to indicate the difference between the two ends of the station. In the transformer-house provision has been made for two banks of 2,100-K.W. transformers from the transmission line at 60,000 volts and delivering to the distribution at 30,000. The high-tension leads are tapped from two of the outgoing 60,000-volt circuits in the switching-house, and after passing through oil switches join in a common bus from which the transformers can be separated by means of knife-blade switches.

This switch-gear, with the exception of the transformer switches, is on a concrete deck forming a complete second story in the switching-house, 18 feet above the floor. On the under side of this floor there are also mounted the insulators for the 30,000-volt circuits. The 30,000-volt oil switches are, however, placed on top of the floor. The lightning arresters for the 60,000-volt circuits are on the wall between the transformer, and the switch-house, and are separated from each other by 6-foot barriers, while the 30,000-volt arresters are against the end of the substation immediately below the oil switches and the outgoing 30,000-volt circuits.

At Castaic there will be installed at present one bank of transformers, 2-100 K.W., oil-filled and water-cooled. These transformers will supply power to a 30,000-volt, 40-mile transmission

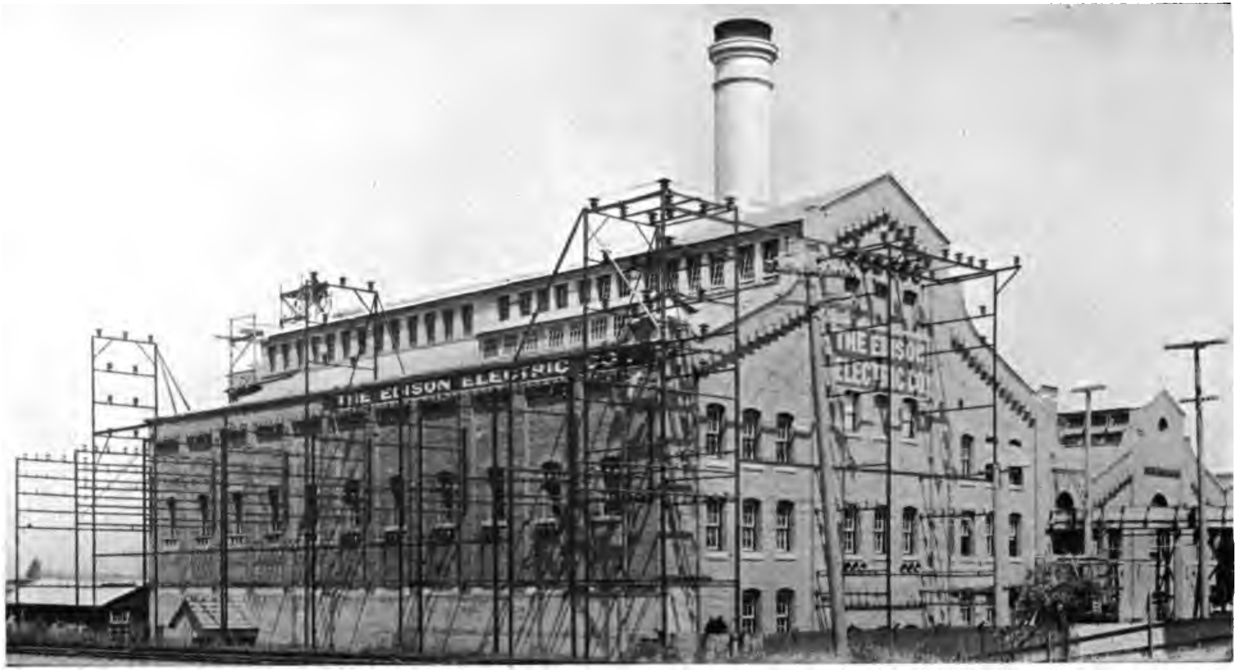



Fig. 156.—Exterior of Los Angeles Receiving Station.

system now being built by the Ventura County Power Company, west from Castaic to Saticoy, where a branch is taken off at Oxnard, while the main line continues to Ventura. This branch will eventually be continued to Santa Barbara, 30 miles farther, where the Edison Electric Company has extensive power and railway holdings.

At San Fernando is a 1,200-K.W. bank, which will supply power at 2,300 volts to lamps and motors.

*Los Angeles Receiving Station.*—The Kern River No. 1 transmission line terminates in Los Angeles, 117 miles from the power

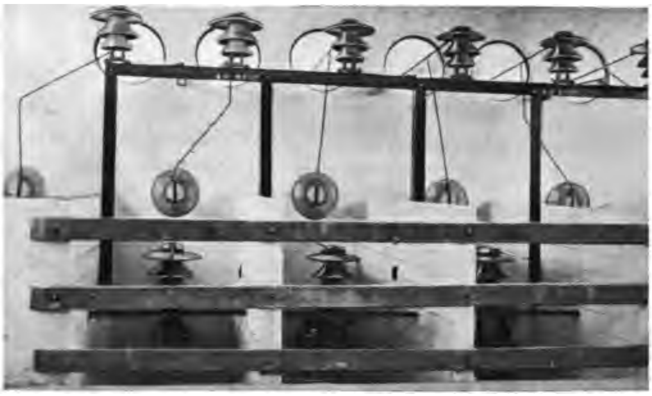


FIG. 157.—LINES ENTERING LOS ANGELES RECEIVING STATION.

plant, at the steam and transformer station known as Los Angeles No. 3. This station is constructed to receive, transform, and distribute to the local substations, power transmitted from the company's water-power plants on Santa Ana River, Mill Creek, Lytle Creek, and Kern River, and also contains a large steam auxiliary plant to supplement the water-generated power. It receives power at 60,000 and 30,000 volts, and generates and distributes at 16,000 and 2,300 volts.

Both of the Kern River circuits enter the station through the east gable, as shown in Fig. 156. After passing through choke coils the lines enter oil switches which connect them to their re-

spective bus-bars. There is also an oil tie switch between the two buses. Each transformer has an oil switch which can be connected by means of a double-throw knife-blade switch to the bus-bars belonging to the west or to the middle circuit. When the east circuit comes in, it will have a pair of oil switches so that it can be run on either of the bus-bars.

There are four step-down 4,500-K.W. transformer banks, with their secondaries wound for either 16,000 or 32,000 volts. Under ordinary conditions, all energy received from Kern River will be handled through the double 15,000-volt bus. The transformers are cooled by forced-oil circulation. The oil, after leaving the transformer, is handled in the same manner as at Kern River. It enters a receiver, is forced by variable-speed centrifugal pumps into boiler-tube cooling coils outside the building, and passes back into the pressure line which fills the transformers. There being no extensive supply of cold water available, the cooling water is circulated continuously from the oil cooler basin into elevated troughs, from which it drops over a series of screens, where it is cooled immediately before falling on the section containing the hot oil.

This building also contains provision for switching the old 30,000-volt, 80-mile transmission line, fed by the Santa Ana and Mill Creek plants, with its various branches and all the 15,000 volt distribution around Los Angeles. The arrangement of the various circuit bus-bars, oil switches, and the transformers is shown in the accompanying diagram. All switches and circuits are controlled from a 12-panel switchboard on the gallery of the turbine-room, which is equipped with the necessary control switches and instruments for the 60,000-, 30,000-, 15,000-, and 2,300-volt buses.

All bus-bar wiring connections to the transformers and the outgoing circuits are carried in ducts. In the new portion of the station these are filled with 15,000-volt leaded paper cables of 211,-000-cm. cross-section, with the exception of those for the turbo-generator, which has 400,000-cm. cables.

There were installed in the steam end of this plant during

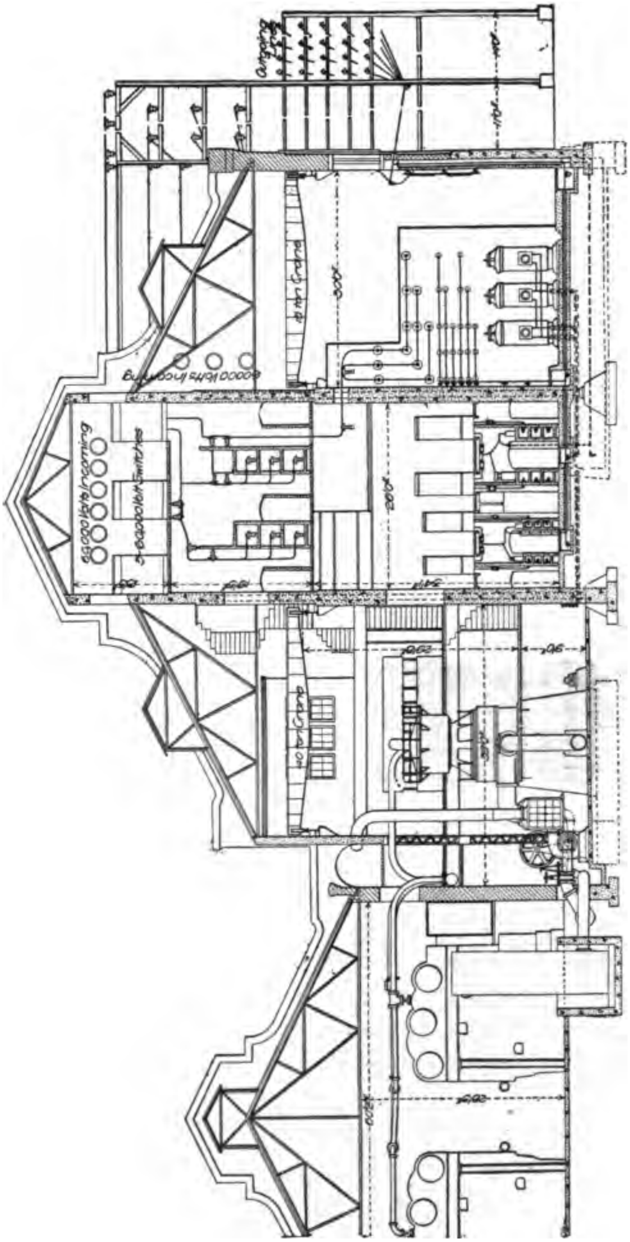


FIG. 158.—SECTION OF LOS ANGELES RECEIVING STATION.

1903 two 2,000-K.W. 2,300-volt turbo-alternators, with 4,000 H.P. of water-tube boilers, in 500-H.P. units. When it became necessary to order an extension for the plant, in 1905, larger-size apparatus was determined upon throughout. An additional 5,250 H.P. in 750-H.P. units was installed in the boiler-room.

The turbine installation in the new plant consists of a single 6,000-K.W. turbo-alternator, with condensing equipment. This unit is four-stage, single-flow, and is operated at from 27½-inch to 28-inch vacuum. Thus far loads up to 10,000 K.W. have been carried on the machine without any indication of its maximum load being approached.

The generator is wound for 16,500 volts, star connected, and is run with grounded neutral on the 50-cycle distribution of the company. The generator operates perfectly and runs in multiple with the main system without causing any disturbance whatever. Between the neutral of the machine and the station ground wire, a potential difference of several hundred volts exists under operating conditions, with the machine in connection with star-to-delta-connected transformer banks. This voltage and the resultant flow where the neutral switches close, vary with the number of transformers and the load on them, but does not appear to vary from other causes. An observation of the wave shape across the neutral connection showed a somewhat peaked potential wave at three times the frequency of the main circuit. For the present, the exchange current is limited by the insertion of the choke coil in the neutral connection. At a later date a resistance will be substituted for the coil. This phenomenon in one shape or another is observable on all Y-connected four-wire generator installations.

A transformer bank stepping from 15,000 to 2,200 volts is connected to the machine leads so that the auxiliaries can be transferred to the generator leads after the unit is in full operation.

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